

State-of-the Art Environmental Assessment of
Onshore Disposal of Manganese Nodule Rejects

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**STATE-OF-THE-ART
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OF ONSHORE DISPOSAL OF
MANGANESE NODULE REJECTS**

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Rogers, Golden & Halpern

**BUREAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR
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FOREWORD

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PATENT STATEMENT

This report does not contain patentable information.

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ABBREVIATIONS AND ACRONYMS

AFB	- air force base
ASARCO	- American Smelting and Refining Co.
BAT	- best available technology economically achievable
BCT	- best conventional pollutant control technology
BLM	- U.S. Bureau of Land Management
BMP	- best management practices
BPT	- best practicable control technology currently available
BuMines	- U.S. Bureau of Mines
CAA	- Clean Air Act
CCA	- California Coastal Act
CEQ	- Council on Environmental Quality
CEQA	- California Environmental Quality Act
cm/sec	- centimeters per second
cm/yr	- centimeters per year
COE	- U.S. Army Corps of Engineers
CPPR	- Consolidated Permit Program Regulations
cu m	- cubic meters
CWA	- Clean Water Act
CZM	- coastal zone management
CZMA	- Coastal Zone Management Act
DHS	- California Department of Health Services
DLNR	- Hawaii Department of Land and Natural Resources
DOH	- Hawaii Department of Health
DOI	- U.S. Department of the Interior
DOMES	- Deep Ocean Mining Environmental Studies
DPED	- Hawaii Department of Planning and Economic Development
DSHMRA	- Deep Seabed Hard Mineral Resources Act
DWR	- Texas Department of Water Resources
dwt	- deadweight tons
EA	- environmental assessment
ECPA	- Washington Environmental Coordination Procedures Act
EIR	- environmental impact report
EIS	- environmental impact statement
EP	- Extraction Procedure
EPA	- U.S. Environmental Protection Agency
EQL	- Hawaii Environmental Quality Law
ESA	- Endangered Species Act
ft/mi	- feet per mile
FWCA	- Fish and Wildlife Coordination Act
FWPCA	- Federal Water Pollution Control Act
FWS	- U.S. Fish and Wildlife Service
gal/day	- gallons per day
gal/min	- gallons per minute
gal/sq ft/day	- gallons per square foot per day
ha	- hectares
HWDA	- Washington Hazardous Waste Disposal Act
in/yr	- inches per year
km	- kilometers
m	- meters
MBTA	- Migratory Bird Treaty Act
µg/cu m	- micrograms per cubic meter

mg/l	- milligrams per liter
mi/hr	- miles per hour
MMPA	- Marine Mammal Protection Act
MSHA	- U.S. Mine Safety and Health Administration
mtpy	- metric tons per year
Mw	- megawatts
NAAQS	- national ambient air quality standards
NEPA	- National Environmental Policy Act
NHPA	- National Historic Preservation Act
NMFS	- National Marine Fisheries Service
NOAA	- National Oceanic and Atmospheric Administration
NPDES	- National Pollutant Discharge Elimination System
NPS	- National Park Service
NRC	- U.S. Nuclear Regulatory Commission
NTIS	- National Technical Information Service
NWPS	- National Wilderness Preservation System
NWSRS	- National Wild and Scenic Rivers System
OTEC	- ocean thermal energy conversion
P&E	- prospecting and exploration
PEIS	- Programmatic Environmental Impact Statement
PHADA	- Preservation of Historical and Archaeological Data Act
PHS	- U.S. Public Health Service
ppm	- parts per million
PSD	- Prevention of Significant Deterioration
RARE	- Roadless Area Review and Evaluation
RCRA	- Resource Conservation and Recovery Act
R&D	- research and development
RWQBC	- California Regional Water Quality Control Board
SCS	- U.S. Soil Conservation Service
SDWA	- Safe Drinking Water Act
SEPA	- Washington State Environmental Policy Act
SIP	- State implementation plan
SLC	- California State Lands Commission
SMA	- Special Management Area
SPM	- single-point mooring
sq km	- square kilometer
SWMB	- California Solid Waste Management Board
SWMRRA	- Washington Solid Waste Management Recovery and Recycling Act
SWRCB	- California State Water Resources Control Board
TDS	- total dissolved solids
tpy	- tons per year
TSCA	- Toxic Substances Control Act
TSP	- total suspended particulates
UIC	- underground injection control
UNCLOS III	- United Nations Third Conference on the Law of the Sea
WDOE	- Washington State Department of Ecology
WSMA	- Washington Shoreline Management Act
WSRA	- Wild and Scenic Rivers Act

EXECUTIVE SUMMARY

The ocean mining of manganese nodules is of interest to the United States government because of the strategic importance of nickel, cobalt, manganese, and other minerals contained in the nodules, for which the U.S. currently has a high net import reliance. In anticipation of the development of a deep seabed mining industry, the National Oceanic and Atmospheric Administration (NOAA) has been studying the environmental effects related to the development of this industry since 1975. Since 1980, NOAA and the U.S. Bureau of Mines (BuMines), the Environmental Protection Agency (EPA), and the Fish and Wildlife Service (FWS) have been engaged in a cooperative research program developed by an industry-government working group on the management of manganese nodule processing wastes. The program includes this study.

The overall objective of the research program is to provide information needed by Federal and State agencies in preparation for receipt of commercial waste management plans from deep seabed mining ventures. This study for the Bureau of Mines was conducted for the following reasons:

- (1) to identify all reasonable state-of-the-art and emerging state-of-the-art techniques for the **onshore** disposal of various types of manganese nodule processing rejects;
- (2) to provide industry, government, and the public with a first-order assessment of applicable regulatory requirements and important environmental considerations for reasonable combinations of classes of reject, classes of waste disposal technique, and conditions specific to sites representative of those likely to be chosen by industry; and
- (3) to guide research on the characteristics of rejects and field testing and refinement of nodule waste disposal techniques through identification of those chemical and physical characteristics of rejects that are of greatest significance in predicting environmental effects.

The schedule of the research program is designed to provide the information required for assessment of reject disposal both onshore and offshore, prior to 1988, when commercial mining can begin under U.S. legislation. In order to meet the third objective above, this study was completed during the first half of the BuMines Avondale (Maryland) Research Center's ongoing three-year reject characterization study, which is also part of the cooperative research program.

The methods used by this study were based on literature reviews and telephone contacts and direct interviews with knowledgeable persons. No physical or chemical testing of nodule rejects or analogous material was performed under this contract, as the Avondale Research Center characterization study includes such testing in its scope of work. The respective experience of Golder Associates in mineral waste disposal and EIC Laboratories in mineral processing and manganese nodules were relied on heavily to identify likely waste disposal techniques and processing routes with associated types of rejects. Rogers, Golden & Halpern's experience in facility siting, supplemented by previous studies and data-gathering trips to each region of interest specified in the statement of work, were used to develop site selection considerations and to select five "representative sites" for conducting environmental assessments. These sites are representative of the wide range of conditions likely to be encountered at waste disposal sites proposed by industry but are not actual industry sites.

Regulatory regimes at the Federal level and at the State level for each of the four States containing a representative site were reviewed from previous environmental studies for manganese nodule-related activities and updated to reflect current and pending regulations. Regulations relevant to nodule reject disposal were emphasized.

The dimensions of the environmental assessment in this study are the processes to recover value metals from nodules, the applicable waste disposal techniques, and the sites.

Processes

Rejects from six processes identified as likely for first-generation nodule operations were grouped into three classes with one subclass:

- o leached tails from three-metal hydrometallurgical processes and lime boil solids if produced
 - residues from these processes with some manganese removed by physical separation techniques
- o slags from smelting processes and from silico- or ferromanganese produced from manganese recovered from tailings (and from electrolytic manganese production if appropriate)
- o leached tails from four-metal hydrometallurgical processes and residues produced from electrolytic manganese reduction steps (if not slags).

Waste Disposal Techniques

Ten waste disposal techniques discussed in this report were grouped into four classes based on similarity of potential effects: above-surface retention structures; specially excavated pits/backfill of mines/deep disposal; "dewatered" tailings disposal (including slag); and liquid waste disposal (evaporation/deep well injection).

Sites

One representative site was chosen from each of five siting regions: the Pacific Northwest, Southern California, the Gulf Coast, Hawaii (wet climate), and Hawaii (dry climate).

The environmental assessment could potentially have considered 60 process/waste disposal technique/site combinations (3 classes of process X 4 classes of disposal technique X 5 representative sites). However, some combinations were not realistic, such as retention structures for slags, and these were not assessed.

The assessments first rated the significance of 20 potential effects (see **Potential Effects**) by waste disposal technique (table 10). Then modifications to these ratings based on the classes of reject were discussed. Finally for each site, effects that were potentially a problem for a waste disposal technique and type of process reject were evaluated for their significance at each site (tables 11-15).

The environmental assessments are based on subjective judgments by the project team as to which considerations are important at each site, integrating the information on waste disposal techniques, and the characteristics of the rejects and the sites developed during this study.

The principal conclusions of this study are:

- (1) **There is available waste disposal technology applicable to onshore manganese nodule reject disposal, so no new research and development work appears necessary.** In fact, the disposal techniques indicated as likely for a first-generation nodule operation are generally analagous to current techniques for mineral wastes from terrestrial operations. One major exception is that the "tailings" dam for rejects will probably be built from on-site soils or borrow material rather than from the coarse fraction of tailings, as hydrometallurgical process rejects are expected to be too fine to be used in embankment construction. The most innovative waste disposal techniques identified are being applied to uranium tailings, which require much stricter control than appears necessary for nodule rejects.
- (2) **There is an in-place regulatory regime in all regions studied; however, there could be serious delays because of existing permitting procedures for waste disposal facilities.** Uncertainty on the status of nodule rejects with regard to the exemption of mining and mineral processing wastes from Resource Conservation and Recovery Act (RCRA) hazardous waste regulations and possible EPA classification of hydrometallurgical process tailings as hazardous (toxic) are important regulatory issues at all sites. Stricter hazardous waste regulations than RCRA regulations in California and pending modifications to the Washington Hazardous Waste Disposal Act are regulatory issues in these states.

State waste disposal regulations we reviewed did not, in general, anticipate a solid waste disposal facility, particularly for hazardous waste, on the scale required for nodule rejects. Air quality classification regarding total suspended particulates is currently an issue in parts of Southern California, including the representative site.
- (3) **Slags from nodule processing are expected to be inert and could be disposed of at all sites with very little monitoring.** Disposal of slags, once confirmed to be vitreous, inert material, would not be expected to have undesirable environmental effects. In fact, beneficial uses such as land fill and construction aggregate may obviate the disposal problem.
- (4) **The environmental assessment indicates three types of concerns: concerns common to all sites; concerns common to specific areas or regions; and quite site-specific concerns.** An example of the first type of concern is aquifer contamination, which applies to all sites except those with no usable groundwater or with proven adequate geologic barriers to groundwater contamination. The water balance between precipitation and lake evaporation (that is, wet or dry climate) is an example of the second concern. Typically, the water balance applies to large regions (siting regions or parts of siting regions) and influences effects such as fugitive dusts and tailings stability. Site-specific concerns such as wildlife attraction to tailings impoundments can usually be controlled by siting,

although the nature of the region may force a trade-off between concerns. Concerns related to distance from the coast are typically avoided by siting.

- (5) **The primary need for further study identified in this report is the toxicity of three-metal and four-metal hydrometallurgical process tailings.** This characteristic as measured by the EPA Extraction Procedure Toxicity Test determines whether hazardous waste disposal regulations apply (assuming no RCRA exemption for manganese nodule rejects). Because of questions about how well the test replicates actual leaching conditions, an alternate test procedure, the American Society for Testing and Materials Shake Extraction Test, is recommended to provide a comparison to the EPA test procedure. Additional needs for further study that we have identified are as follows:

- o physical property testing of three- and four-metal hydrometallurgical tailings, especially particle-size distribution, settled density, and rate of consolidation;
- o other chemical property testing for hydrometallurgical process rejects;
- o confirmation of predicted physical and chemical characteristics of slags;
- o flow sheets and reject characteristics for three-metal processes with manganese recovery from tailings;
- o physical and chemical characteristics of manufacturing wastes unique to nodule processing;
- o slurry characteristics for hydrometallurgical process wastes; and
- o disposal of slurried nodule wastes in extremely wet climates.

In most cases these studies are more appropriate for rejects from a pilot plant and results from laboratory processes would have to be interpreted cautiously. The above tests are discussed in detail in the section **Needs for Further Study** beginning on page 149.

INTRODUCTION

Overview

Manganese nodules are concretions which are found on the seabed of deep (-4000 to -5000 m) ocean basins and the bottoms of some lakes and inland seas. Most nodules range from grapes to potatoes in size and shape. They are composed chiefly of metallic oxides, usually occurring as crusts which have slowly accumulated layer by layer on some nucleus such as a small rock or shark's tooth. Current interest in manganese nodules focuses on their nickel, copper, cobalt, and manganese content. Other metals found in nodules, such as molybdenum, may be of economic interest by the time an industry develops. Extensive exploration by industry and scientific organizations has revealed that the nodules which are currently of greatest commercial interest are those located in the near-equatorial northeastern Pacific Ocean in the Clarion-Clipperton Fracture Zone. This area extends from south of Hawaii to south of the Baja peninsula (180°W longitude to 110°W longitude).

The mining of manganese nodules from the deep seabed can provide a valuable new source of nickel, cobalt, manganese, and other nonferrous metals for which the United States is almost totally dependent on foreign sources. Deep seabed mining by domestic interests would provide the United States with a stable supply of these strategic metals, which are now imported, in some cases from politically unstable areas.

Four multinational consortia with U.S. members are engaged in the development of a nodule mining and processing industry. These consortia--Ocean Minerals Co., Ocean Mining Associates, Ocean Management, Inc., and the Kennecott Consortium--have successfully tested small-scale mining operations and have been processing recovered nodules in laboratory and pilot-scale facilities. Significant amounts of money have already been spent by these companies to investigate nodule mining. Further investment will depend upon the terms of the treaty being developed at the United Nations Third Conference on the Law of the Sea (UNCLOS III). The current draft of the treaty proposes that manganese nodule deposits on the high seas be regulated by an International Seabed Authority, and that the proceeds of mining be shared. In the absence of a satisfactory treaty, unilateral national legislation has been passed by the United States and West Germany. The Deep Seabed Hard Mineral Resources Act (DSHMRA) establishes an interim regulatory regime under which U.S. companies can obtain licenses for exploration (after July 1, 1982) and permits for commercial recovery of nodules (to begin no earlier than 1988) pending an international treaty.

Assuming that the technological, legal, and economic obstacles to a manganese nodule mining industry can be eliminated, commercial mining and first generation (onshore) processing plants could begin before 1990.

In order to recover the value metals from the nodules there are 12 or more available process routes--either hydrometallurgical processes or combined pyrometallurgical/hydrometallurgical processes. Whatever route is used, disposal of the process wastes--called rejects--is potentially a major problem in manganese nodule processing. For Pacific nodules, copper, nickel, and cobalt are about 2.5-3% of the dry nodule by weight and manganese is about 25-30%. Therefore, solid wastes in a plant that recovers only the first three metals will amount to approximately the same weight as the initial weight of the nodules mined--up to 4 million wet metric tons per year (mtpy) (4.4 million tpy) for one operation. The amount of waste in a plant that also recovers manganese will be less but still significant.

In addition to the value metals, nodules have many other constituents. Several of these constituents, which are tightly bound in the matrix of the nodule and are in low concentration, are considered toxic in either their elemental forms or in certain compounds. While the constituents are considered inert as the nodules appear in nature, the extent to which they will be transformed during processing, the proportion that will be in the rejects, and proportion that will be impurities in products are currently not known. Until those process routes that are still under development by industry are tested at a larger scale and in a manner more closely resembling a commercial operation, no rejects that can be considered representative will be available for testing. Some questions will remain until commercial rejects can be sampled and tested.

Because of the large volume and the unknown chemical and physical nature of the wastes, the U.S. Bureau of Mines (BuMines), National Oceanic and Atmospheric Administration (NOAA), Environmental Protection Agency (EPA), and Fish and Wildlife Service (FWS) have begun a series of cooperative projects in research on manganese nodule processing waste management. The present study is one of the initial projects in this program. The overall objective of the cooperative research program is to provide information needed by Federal and State agencies in preparation for receipt of the marine mining industry's commercial waste management plans. The objectives of this study are threefold: (1) to identify all reasonable state-of-the-art and emerging state-of-the-art techniques for the onshore disposal of various types of manganese nodule rejects; (2) to provide industry, government and the public with a first order assessment of applicable regulatory requirements and important environmental considerations for combinations of classes of reject, waste disposal techniques and site conditions; and (3) to assist in establishing priorities for research on the characteristics of rejects and field testing and refinement of nodule waste disposal techniques.

At least one major Federal action requiring an environmental impact statement (EIS) or an environmental assessment (EA) of onshore disposal under the National Environmental Policy Act (NEPA) is expected to occur with the development of commercial deep seabed mining. A state-of-the-art environmental assessment is necessary at this time, in order that field testing and refinement of nodule waste disposal techniques can be completed prior to 1988.

Background on Manganese Nodule Mining Ventures

Development of the technology and facilities necessary for the mining and processing of manganese nodules as a commercially viable operation will require the commitment of many hundreds of person-years of effort over an extended period of time and, by recent estimates, the expenditure of more than \$1 billion. Operation of a processing plant and the disposal of rejects produced during the extraction of value metals from the nodules are only two of the many elements of the venture.

The early activities in a nodule mining venture involve prospecting and exploration (P&E) at sea to delineate the characteristics of the resource, and research and development (R&D) activities on land to develop the technology to retrieve the nodules from the ocean floor and process them to recover the desired products. Both P&E and R&D activities will be initiated on a small scale and expanded in scope as technical and economic success is attained at a series of milestones in the project. P&E activities will evolve from survey work over large areas to detailed mapping of prospective mine sites with the retrieval of a sufficient amount of nodules to support bench- and pilot-scale R&D work on the development of processing routes. R&D on mining systems will involve the design and testing of small-scale prototype collectors and lifting equipment which

would be tested from modified research vessels, and will lead to the construction of full-scale equipment and the development of specifications for specially designed mining vessels.

R&D work on the processing of the nodules would be initiated in the laboratory where the basic extractive metallurgy would be defined. The process concept would then be tested at larger scales in order to obtain design data for a commercial-scale plant. Sufficient quantities of nodule rejects would be produced in this operation to obtain data on their physical and chemical properties and to evaluate potential waste disposal techniques and problems.

A nodule mining and processing venture may be considered to consist of six essential elements: mining and at-sea storage, transportation to port, unloading and storage at the port, transportation of raw nodules to and rejects from the processing plant, nodule processing for metals recovery, and rejects disposal. In addition, the communities in which the land-based activities occur must provide the local infrastructure necessary to support them. While the mine site may be fixed, the developer will select the location of the port, processing plant, and waste disposal area to optimize the total venture, not any one element of it. For example, higher transportation costs might be incurred to site the processing plant at a location where abundant and relatively inexpensive energy is available.

Since the nodule processor will have the opportunity to obtain necessary data on the properties of nodule rejects early in the development program, it should be possible to support the permitting activities for siting the onshore test units and commercial plants with necessary information on waste disposal requirements.

Chronology of Related Environmental Studies

Since 1975 the U.S. government, primarily through NOAA, has been studying the environmental effects related to development of a domestic manganese nodule mining industry. The research has been divided into several programs, each with several studies or phases. The environmental studies within these programs are described briefly in the following paragraphs to provide a context for this project.

Deep Ocean Mining Environmental Studies (DOMES)

Early research focusing on manganese nodules included physical and biological oceanography as well as marine geology. NOAA initiated the DOMES project primarily as a 5-year (1975-1980) data-gathering effort in two phases. The purpose was to identify possible environmental effects that might occur from eventual commercial exploitation and to provide information useful to the development of environmental guidelines for controlling such exploitation. DOMES I provided environmental baseline information on potential deep sea mining locations in the Pacific nodule province. Final data reports from the DOMES I project were submitted to NOAA in 1978 (21)¹.

DOMES II involved the monitoring of industry's at-sea pilot-scale mining simulations in 1978 and 1979. The emphasis was on observing actual effects to enhance environmental predictive capabilities from DOMES I. Results of DOMES Phase II

¹Underlined numbers in parentheses refer to items in the list of references at the end of this report.

incorporated in the Programmatic Environmental Impact Statement (PEIS) required by DSHMRA. Investigator reports were submitted to NTIS but not summarized in a separate publication other than the PEIS.

Studies of Potential Environmental And Socioeconomic Effects Associated with Manganese Nodule Processing

NOAA has also conducted a multiphased program to assess the potential environmental and socioeconomic effects associated with manganese nodule processing. The first phase was undertaken by Dames & Moore and EIC Corporation (now EIC Laboratories). Three volumes resulting from this phase have been published. The first volume (95), the Processing System Summary, addresses the parameters of manganese nodule processing systems of importance for subsequent assessments of potential effects. Initially, processing techniques were assessed to identify those considered likely for early commercial use and to project the quantities of nodules that each technique would consume annually. It then focuses on developing material and energy balances; identifying wastes produced, resources consumed, and noise generated; describing waste treatment alternatives; and describing at-sea processing alternatives to land facilities. Volume II (80) concentrates on likely sea and onshore transportation systems and alternative waste disposal methods. The third volume (96) presents a more detailed analysis of manganese nodule processing along with an annotated bibliography.

The second phase consisted of studies to identify geographical areas representative of those of potential interest to the manganese nodule industry for the siting of onshore processing and related facilities. One study for the West Coast, including Alaska, was prepared by Victor Neal of the Oregon State University School of Oceanography in 1977 (312). A second study, for the Gulf Coast, was prepared by Daniel Bragg of the Industrial Economics Research Division of the Texas A.&M. University Sea Grant Program and was published in August 1979 (34). The purpose of these studies was to provide information that NOAA could subsequently use to determine to what extent effects would change based upon the location of processing activities. More details of these studies are provided in this report within the section **Representative Sites for Onshore Nodule Reject Disposal**.

The State of Hawaii Manganese Nodule Program

The State of Hawaii Department of Planning and Economic Development (DPED), the University of Hawaii, and the local business community have been studying manganese nodules since 1969. A 1969 report by DPED, Hawaii and the Sea, and a 1974 report also entitled Hawaii and the Sea by the Governor's Advisory Committee on Science and Technology, suggested possible support roles for Hawaii in developing a manganese nodule industry.

In 1975 the Hawaii State Legislature provided funding to begin a manganese nodule program designed to assess the potential of a nodule processing industry in Hawaii (154). A DPED-assembled study group of consultants and university experts began research in 1977. The resulting study, The Feasibility and Potential Impact of Manganese Nodule Processing in Hawaii, was published in February 1978 (378). The study assumed a hypothetical plant location with ocean disposal of tailings and focused on the economic aspects of the industry.

During late 1977, NOAA's Marine Minerals Division (now merged into NOAA's Office of Ocean Minerals and Energy) and DPED agreed that it would be mutually

advantageous to engage in a more comprehensive study. In this study, additional process options and additional required transportation systems and transportation options were considered, and use of onshore disposal of rejects was added. It was decided to study one illustrative site on the windward (wet) side of the Big Island and another illustrative site on the leeward (dry) side of the island. Collaboration to obtain input continued in 1978, 1979, and 1980 between NOAA and industry, consultants, academia, and the public; a technical review meeting was held in Honolulu during April 1979 and a public workshop was held in Hilo, on the island of Hawaii, during August 1979. The project resulted in a publication entitled The Feasibility and Potential Impact of Manganese Nodule Processing in the Puna and Kohala Districts of Hawaii (176). This study is the most comprehensive environmental assessment of manganese nodule processing at a specific location that has yet been produced. The report provides a general description of the manganese nodule industry, a characterization of Hawaii-based systems, and a preliminary assessment of potential socioeconomic and environmental impacts of the construction and operation of a manganese nodule processing plant.

Studies Regarding Federal and State Regulations Applicable to Manganese Nodule Processing

In order to support its activities in preparing the Programmatic Environmental Impact Statement required by DSHMRA (405), NOAA has sponsored two studies to determine applicable State and Federal regulations. These studies discuss laws affecting nodule processing activities, including, but not limited to, waste disposal.

An Analysis of Applicable Law Concerning Seabed Mineral Processing in California, Washington, Oregon and Alaska (304), undertaken by the law firm of Nossaman, Krueger and Marsh, was commissioned by NOAA in recognition of the need for in-depth information on the Federal and State laws affecting the siting, construction, and operation of manganese nodule processing plants and associated facilities in California, Washington, Oregon, and Alaska. It presents a compilation and analytical summary of pertinent West Coast laws, especially environmental and land use, and identifies regulatory entities and roles, impediments, gaps, and incentives. When possible, the report estimates the time required for various permit processes. The analysis began in May 1979, and the report was published in May 1980. Technical assumptions are based on information from an earlier NOAA-sponsored report, Description of Manganese Nodule Processing Activities for Environmental Studies (80, 95, 96). The geographical areas on which the study focuses are those "representative areas" previously identified by Oregon State University.

An Analysis of State and Federal Laws Applicable to Manganese Nodule Processing on the U.S. Gulf Coast (33) was recently completed by Boston Technologies, Inc., for NOAA. The purposes of the study were

- (1) to assure that environmental impact statements prepared by the government pursuant to DSHMRA adequately reflect the provisions of and policies expressed by existing law;
- (2) to assure that the requirements and timetables established by existing laws are adequately reflected in regulations issued by the government pursuant to deep seabed mining legislation;
- (3) to facilitate interagency and intergovernmental cooperation and coordination in the implementation of deep seabed mining legislation; and

- (4) to permit a subsequent analysis of "environmental compliance costs" to be used in evaluations of U.S. and foreign processing costs.

The representative geographic locations discussed were those identified by Texas A.&M.

Cooperative Research Program on
Manganese Nodule Processing Waste Management

The cooperative research program mentioned in the **Overview** section includes three initial projects with durations from 1 to 3 years, as shown below.

Project No. 1: Analysis and Characterization of Potential Manganese Nodule Processing Rejects

Sponsor: NOAA Duration: 3 years
Performer: BuMines Avondale Research Center

Project No. 2:
(this project) State-of-the-Art Environmental Assessment of Onshore Disposal of Manganese Nodule Rejects

Sponsor: BuMines Duration: 1 year
Performer: Rogers, Golden & Halpern

Project No. 3: Ocean Disposal State-of-the-Art and Associated Environmental Considerations Relevant to Disposal of Manganese Nodule Processing Rejects

Sponsor: NOAA-EPA Duration: 1 year
Performer: Tetra Tech

These projects were developed by an industry-government working group on the management of manganese nodule processing wastes.

The purpose of the first project is to obtain a chemical and physical characterization of rejects from types of manganese nodule processing technique representative of those being developed by industry. The project includes updating process road maps, generic predictions of the nature of potential rejects, laboratory sampling of rejects from the marine mining industry, and bench-scale processing of nodules with subsequent testing of rejects generated. Draft reports and presentations have been available at various times during this project.

The third study is the offshore counterpart of this study and has similar objectives. It will examine the current and emerging state-of-the-art ocean disposal techniques potentially applicable to nodule rejects. It will also identify and describe the procedures involved in obtaining authorization for each technique and analyze the environmental considerations that relate to the physical and chemical properties of the rejects at representative locations for offshore disposal and ocean outfalls.

Deep Seabed Mining Programmatic Environmental Impact Statement

This PEIS has been prepared by NOAA's Office of Ocean Minerals and Energy, pursuant to DSHMRA and NEPA, to analyze the effect of exploration and commercial

deep seabed mining for manganese nodules. It describes the major aspects of deep seabed mining, potential environmental effects at-sea and onshore to the extent known, and NOAA's plans for exercising its responsibilities under DSHMRA. Included is a section on NOAA's role with respect to onshore activities. The draft PEIS was issued during March 1981 and the final PEIS, which reflected results of comments, was issued during September 1981. As new information is acquired, NOAA may choose to amend, supplement, or update the PEIS. DSHMRA requires a separate, site-specific EIS on each license for exploration and each permit for commercial recovery considered by NOAA.

Other Studies

Additional studies have been performed on the overall economics of manganese nodule ventures, the effects of delay in seabed mining on strategic minerals supply, and the energy implications of deep seabed mining. These are only indirectly related to this project.

Methods of Investigation/Limitations of This Study

The dimensions of this environmental assessment include the processes to recover value metals from nodules, the disposal techniques applicable to nodule rejects, and the sites at which rejects disposal is likely to take place. Within this study 6 processes were identified which were classified into 3 classes with 1 subclass; 10 waste disposal techniques (including beneficial use and 2 types of liquid disposal) were identified which were classified into 4 classes with 1 subclass; and 5 sites were selected as representative of the types of sites likely to be chosen by nodule plant operators. These sites were chosen to reflect a wide range of conditions relevant to waste disposal.

The environmental assessment conducted in this study for five sites and the background search of regulations, processes, waste disposal techniques, and environmental characteristics of the regions in which the sites were located were based on literature searches, telephone contacts and direct interviews with knowledgeable individuals, and site visits to each of the five siting regions and the five sites. No site-specific testing or disposal plans were used, so in this sense the assessments are general.

Each part of the study has its own limitations:

- (1) The analysis of processing options and characteristics of the rejects was based on published information and analogs from terrestrial mining operations. With the exception of limited testing of rejects from one process by BuMines, no laboratory testing of rejects was available. Information on the processes and the rejects relies heavily on previous work by EIC except where new information was available from the background search.
- (2) Waste disposal techniques identified in this study represent primarily available technology and some emerging alternatives that have been applied to comparable wastes. Much of the emerging technology was developed for uranium tailings, which have more stringent disposal requirements than manganese nodules are expected to have. Techniques that were possible but not practical for the volume of waste generated were not considered.
- (3) The analysis of five siting regions attempted to identify sites that were representative of the types of areas likely to be considered by industry or that, taken together, present the range of conditions likely to be encountered in

actual proposals. There is no direct or indirect implication that the sites analyzed are actual, preferred, or optimal.

- (4) In predicting the potential nature of rejects, only Pacific nodules and processing techniques identified with them were considered. Other deposits, for example the Blake Plateau nodules, can be expected to have different nodule characteristics and may require different processing techniques. This would change the predictions used in this study.
- (5) Economic factors were, under the scope of work, only considered implicitly, and some potentially viable plant-siting-related options (such as barging nodules far upstream in major estuaries or far inland rail transportation) were excluded from the study. However, even the implicit consideration of economics reduced the disposal options studied.

MANGANESE NODULE PROCESSING OPTIONS

Selection of a processing scheme for the recovery of valuable metals from manganese nodules by a particular developer will be based on an evaluation of many parameters bearing on technical feasibility, marketing considerations, and project economics. No "optimum" processing technology exists; rather, special circumstances and external variables may favor the adoption of one or another process route to suit the needs of the particular developer. Examples of such special circumstances might include access to a supply of nodules with a particular composition, availability of a particular chemical reagent or power at favorable prices, a special marketing position in one of the recoverable metals in the nodules, site-specific limitations on the disposal of process wastes, and local regulatory considerations.

Summary of Previous Studies/Literature Review

A comprehensive review of the scientific and patent literature on nodule processing options was carried out during the preparation of a study for NOAA describing possible first generation nodule processing routes (95, 96). This review focused on work reported from the mid-1960's to the time of preparation of the study (1977), a time in which a number of industrial consortia were very active in pursuing the development of manganese nodule processing technology. While the literature revealed that a wide variety of processing options were available, it was evident that the bulk of the research and development work was focused on a very few options. The available literature could be classified according to the lixiviant--or chemical solvent--used to dissolve the metals of interest from the nodules as shown in table 1. The classification scheme presented here does not address the critical issue of the manner in which the basic extractive metallurgy of each possible process can be manipulated to result in the development of a completely integrated, economically viable process.

TABLE 1. - Classification of extractive metallurgical process systems

System type	Process description
Sulfate.....	High temperature sulfuric acid leach Smelting/sulfuric acid leach Sulfuric acid reduction leach Reduction roast/sulfuric acid leach Sulfation roast
Ammonia.....	Reduction/ammonia leach CUPRION/ammonia leach High temperature ammonia leach
Chloride.....	Reduction/hydrochloric acid leach Hydrogen chloride reduction roast/acid leach Segregation roast Molten salt chloridation

The fact that the salient chemical and physical properties of nodules resemble those of terrestrial lateritic ores influenced the course of nodule process development work. Since energy costs and capital charges, which are key components in the costs of processing lateritic ores, are likely to be high for nodule processing, other operating costs--particularly lixiviant consumption or loss--must be carefully controlled to obtain favorable economics. The process must be essentially closed with respect to lixiviant use through efficient recycle or regeneration, or a special situation, such as proximity to a reagent manufacturer, must exist with respect to the supply of makeup and disposal of spent materials. This constraint severely limits the possibility of developing viable process routes involving the use of relatively expensive chemical reductants that cannot be easily rereduced for recycle or converted into a valuable byproduct at minimum additional cost.

If it is assumed that nodules of a suitable grade--or metals content--can be obtained for any process option that might be considered, the key decision from a processing point of view is whether or not to recover manganese from the nodules as well as copper, nickel, cobalt, and perhaps other metals such as molybdenum. The recovery of nickel and cobalt from terrestrial lateritic ores is a well-developed technology and was used as the basis for the development of the reductive ammonia/ammonium carbonate and high temperature sulfuric acid leach processes for treating nodules. While these processes do not dissolve manganese, copper is extracted along with the nickel and cobalt, and it became necessary to develop new metal separation and purification techniques. Certain lateritic ores are also treated by pyrometallurgical techniques for the recovery of ferronickel, and the smelting of copper ores is widely practiced. This technology guided the development of processes for the reduction and smelting of nodules, which would permit the separation and subsequent recovery of copper, nickel, and cobalt from the manganese and the recovery of manganese or ferromanganese by further processing, if desired. While energy costs would be significant for such a high temperature process, the cost of the reductant (carbon) is relatively low.

Manganese might also be recovered from the nodules by low temperature hydro-metallurgical techniques involving the reductive dissolution of manganic oxide, the main constituent of the raw nodules. However, development of such a process would require the efficient separation and purification of each metal and effective recovery and recycle of the lixiviant. The latter consideration is the major obstacle to development of processes based on sulfation roasting or reductive leaching involving sulfur dioxide. It can be overcome for chloride reduction/leach processes only because the manganese reduction reactions liberate a relatively pure and valuable byproduct--chlorine--which can be recovered for recycle.

The pace of research and development in nodule processing has apparently decreased in recent years in response to uncertainty with regard to the legal and regulatory regimes under which a nodule processor would be required to operate. In addition, the prices of the metals of interest have not kept pace with the increasing costs of capital and energy. A comprehensive survey of the technical and patent literature published since 1976 shows that no fundamentally new, or even significantly improved, process routes for the recovery of value metals from nodules have been developed in that time period. Two recent reviews (150, 169) summarize the literature in this area and supplement the process bibliography published in 1977 (96). Most recently published papers have simply provided expanded descriptions of process chemistry previously reported.

In the study prepared for NOAA, it was assumed that processing plants would either recover three metals (copper, nickel, and cobalt) or four metals (these plus

manganese) from the nodules. An intermediate processing option, the recovery of manganese from the rejects from a three-metal plant, was recognized but not evaluated since no data had been published that would permit the construction of process flow diagrams and material and energy balances. Some information on the recovery of manganese by this approach has been published recently (197) and the comparative economics have been evaluated (22). This evaluation indicates that such an "add on" option could be as economically attractive as the direct production of four metals by a smelting route, and therefore must be considered as a viable process route.

Likely Processes for First Generation Nodule Processing Plants

Of the 12 generic process types presented in table 1, the most likely process options for the recovery of metal values from nodules in first generation plants are, for three-metal plants, reduction/ammonia leach, CUPRION/ammonia leach, and high temperature sulfuric acid leach; and, for four-metal plants, smelting/sulfuric acid leach, and reduction/hydrochloric acid leach. Three-metal processes with manganese recovery from rejects are also likely. With the exception of the last option, detailed process descriptions, flow diagrams, and material and energy balances have been developed for each processing scheme (96). While the final process configuration developed for any of these routes will undoubtedly differ in detail from these in response to improvements and optimizations resulting from continuing research and development work, the essential features of each process route should remain unchanged in most cases. A possible exception is the reduction/hydrochloric acid leach process, where a variety of other options might be considered for the recovery and purification of manganese metal.

The key plant sections, or operations, for five process options are depicted schematically in figures 1-5. Examination of these process schematics reveals that, while they differ in detail, there are a number of important similarities, which are listed below.

- o All processes consist of a large number of individual operations, each of which may involve a large number of steps and many items of equipment. The processes are highly integrated; that is, streams are recycled within the process and the operation of any step depends on those that precede and follow it.
- o All processes have significant requirements for provision of operating services. These requirements include fuel, power, water, and steam, and the supply of chemicals and reductants such as makeup acid and coke.
- o The amount and composition of wastes from any process depend primarily on the amount of nodules treated, the metals which are removed, and the composition of the raw nodules.
- o Waste materials are produced at many points in each processing sequence, both in the process plants and in the service facilities. It is to be expected that these wastes may differ significantly in amount and in chemical and physical properties from point to point in a process and between processes.

Because of the degree of integration, processes that differ in only a few key steps may have different material and energy requirements and produce differing products and amounts and types of waste. Revision of a key step in an existing process route could result in similar changes.

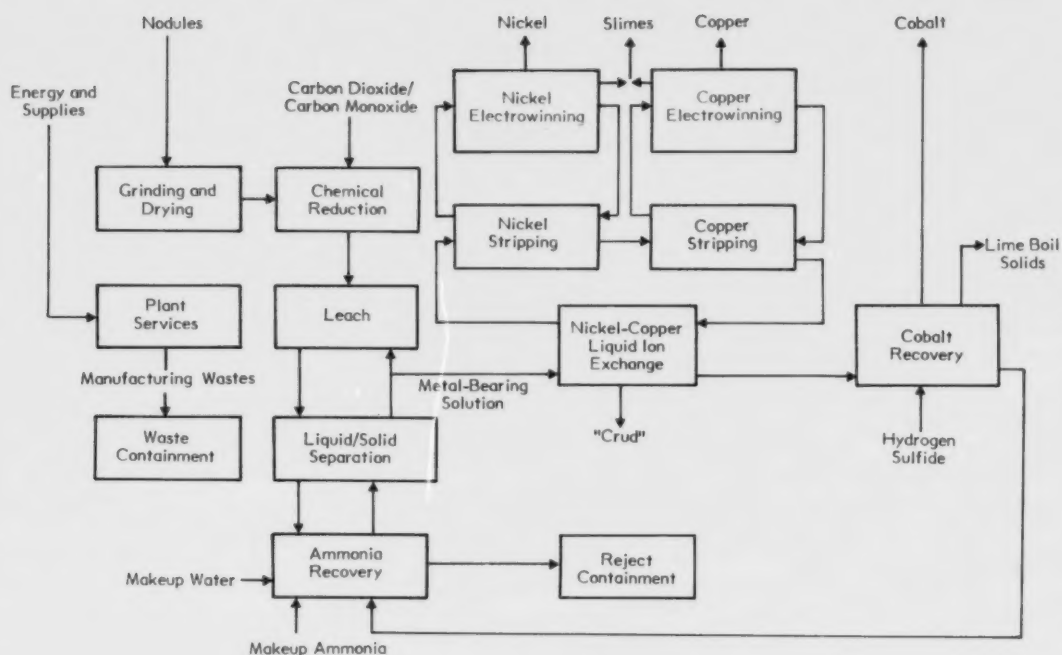


FIGURE 1. - Process schematic for the reduction/ammonia leach process.

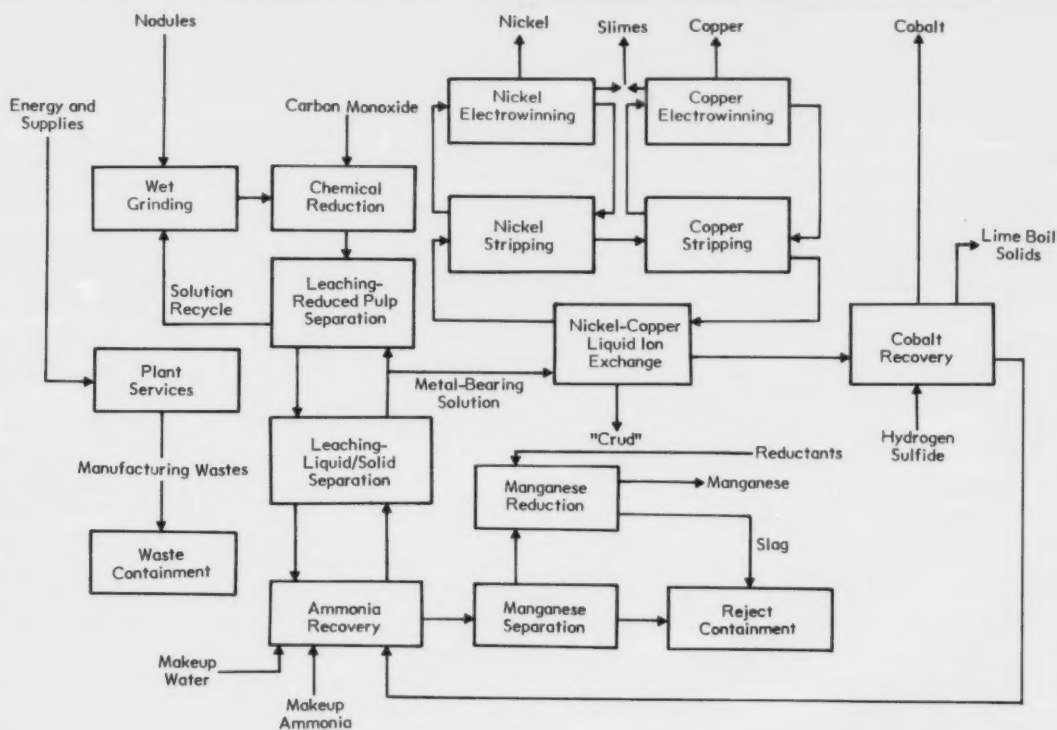


FIGURE 2. - Process schematic for the CUPRION/ammonia leach process with manganese recovery from rejects.

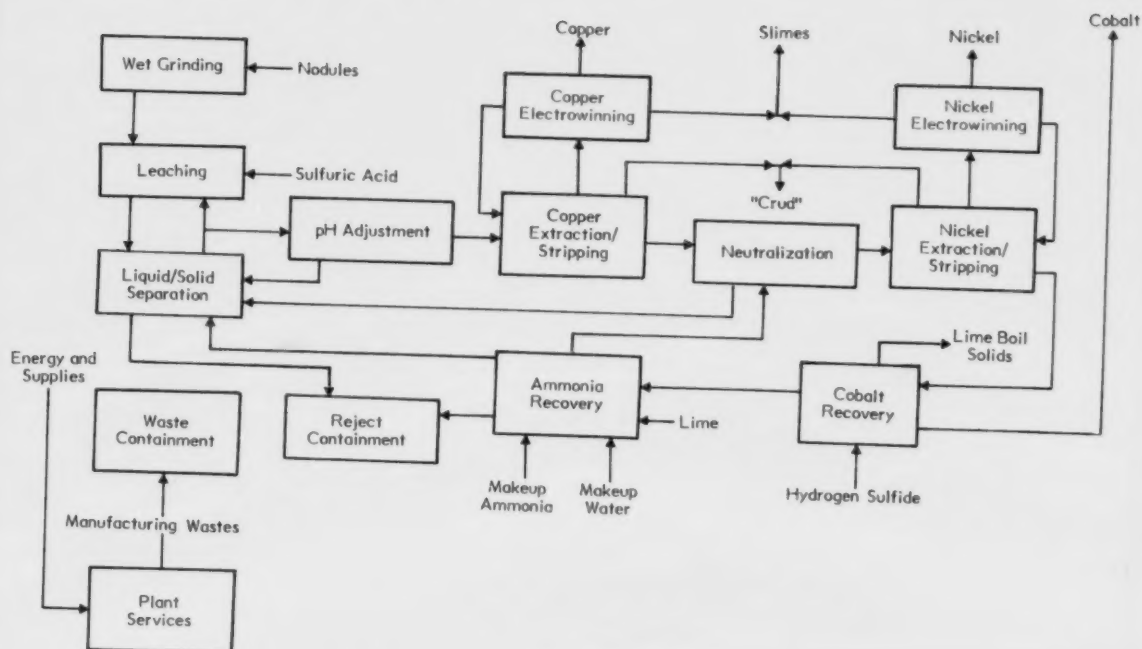


FIGURE 3. - Process schematic for the high temperature sulfuric acid leach process.

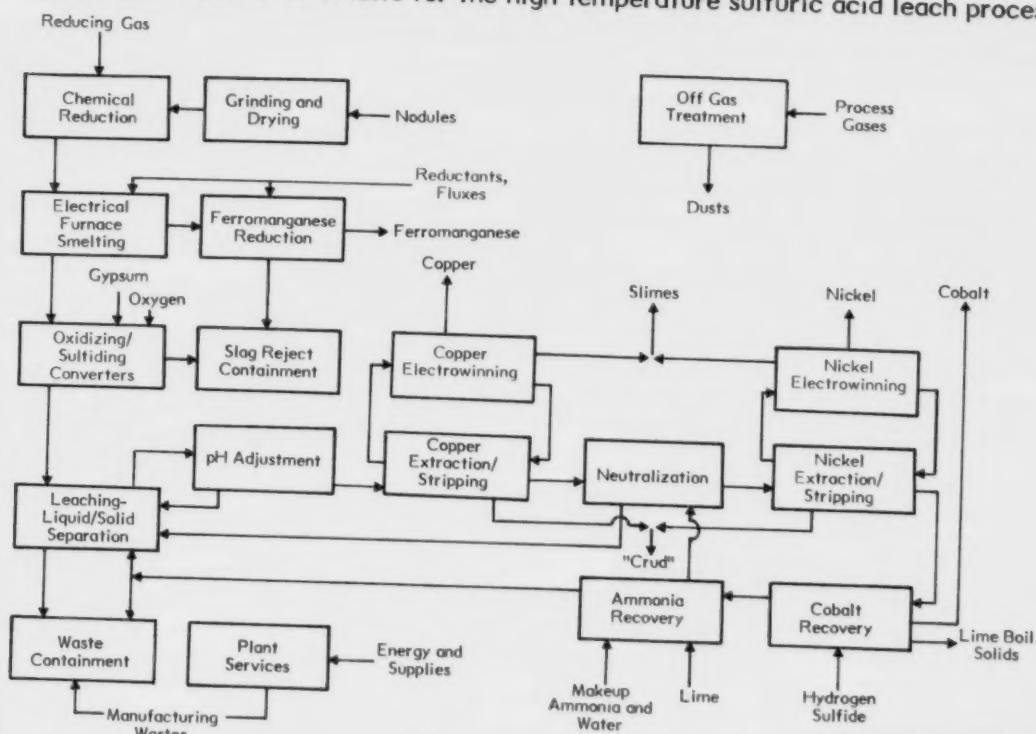


FIGURE 4. - Process schematic for the smelting/sulfuric acid leach process.

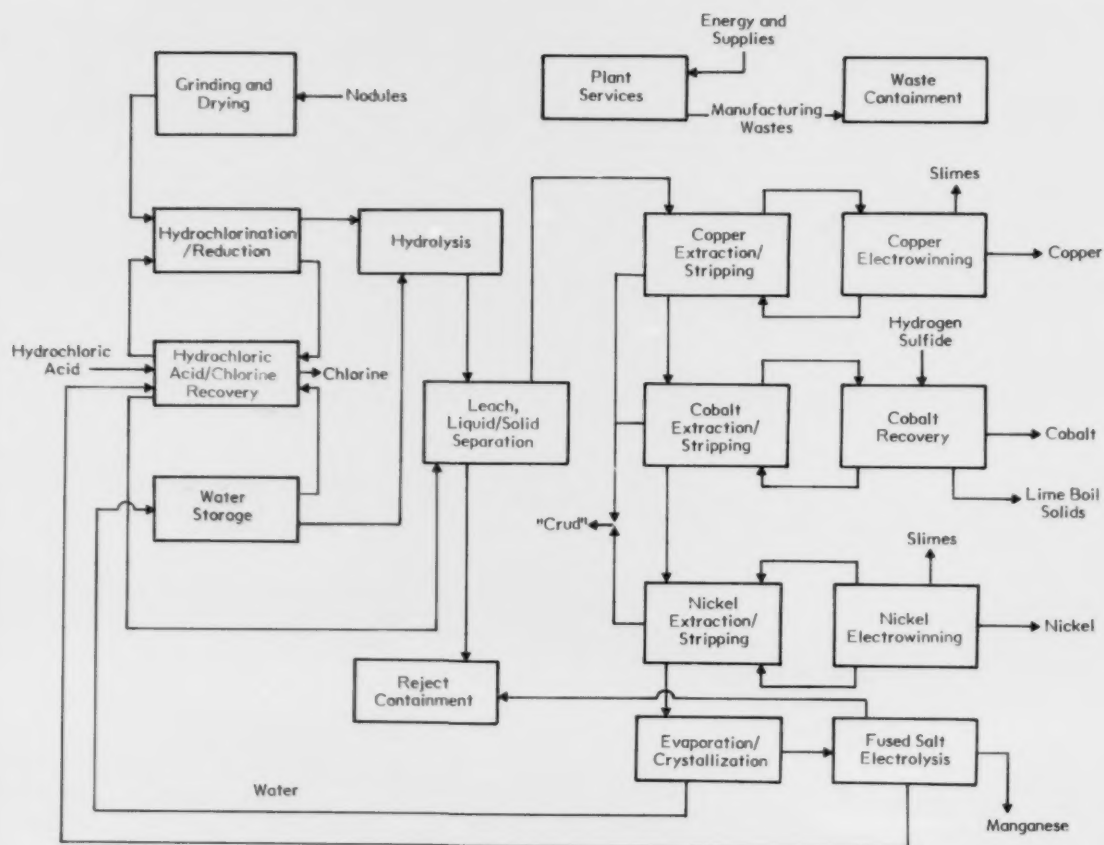


FIGURE 5. - Process schematic for the reduction/hydrochloric acid leach process.

Nodule Mining and Processing Rates

Reported estimates of mining and processing rates for a first generation nodule processing venture have generally ranged from 1.1 to 4 million mtpy (1.2-4.4 million tpy) as mined, with the earlier references tending to cite lower estimates than later ones. The processing rate finally selected by a developer will depend on the balance struck between available economies of scale, market penetration considerations, and the perception of the risks and returns of the venture. Cost and marketing data available 5 years ago led to the conclusion that first generation three-metal plants would process about 4 million mtpy of nodules while four-metal plants would process about 1.5 million mtpy (96). The lower production rate for plants that would produce manganese were thought to be justified because the revenue per ton of nodules would be higher and provide acceptable returns from a smaller operation. In addition, the capital costs of the plant would be higher per ton processed than for a three-metal plant, and the penetration of the manganese market would have to be far greater than for nickel or copper. These considerations suggested a small first generation plant to minimize capital expenditure and marketing uncertainty. Higher production rates are appropriate for three-metal plants because the revenue per ton processed is lower and economies of scale are

required to provide acceptable returns. However, the production of three-metal plants is constructed by the market for cobalt.

More recently, it has been suggested that even four-metal plants would process on the order of 4 million mtpy of nodules (22, 176); these estimates were based on contacts with industry sources. The marketing considerations attending production at these rates has also been reiterated recently (2); the output of one such plant would supply 57% of the total U.S. manganese requirements in all forms. Production of this much electrolytic manganese would exceed current world consumption (22). Information currently available suggests that the situations described below could be expected. All rates are for wet (as mined) nodules.

- o Three-metal plants would be designed to process 4 million mtpy of nodules.
- o Four-metal plants based on a process that recovers ferromanganese from smelting slags would be designed to process 4 million mtpy of nodules. Recovery of manganese to the maximum possible extent could be optional.
- o Four-metal plants based on the recovery of manganese from the rejects from a three-metal plant with subsequent upgrading to ferro- or silicomanganese would be designed to process 4 million mtpy of nodules. Recovery of manganese at lower yields than obtainable from a smelting process is likely.
- o Four-metal plants based on a process that recovers electrolytic manganese would be designed to process 1.1 million mtpy of nodules.

The higher processing rate for a four-metal plant is partly based on the importance of the ferromanganese alloy product and a continuing trend toward increased U.S. importation of manganese alloys in place of manganese ore. The incremental investment to recover ferromanganese has been estimated to yield the same discounted cash flow rate of return as for a three-metal plant (176). This is based on selling 590,000 mtpy (100%) of the ferromanganese. Another source (190) estimates 4.8 million mtpy (wet) processed with only part (28.6%) of the slag stream converted to ferromanganese.

Types and Amounts of Waste Produced in Processing Nodules

The process schematics in figures 1-5 show that a variety of types of waste are produced in the processing of manganese nodules. Material balances have been developed that estimate the amount (176) and bulk composition (96) of wastes from these processes. It is useful in characterizing these wastes to distinguish between those unique to the treatment of nodules and those produced in other manufacturing operations.

Examples of manufacturing wastes include sludges produced from water softening operations, combustion ash and flue gas desulfurization sludge from steam generation, cooling tower blowdown streams, and miscellaneous scrap and trash generated during normal operation and maintenance in the plant. These process wastes are not at all unique to nodule processing, since they are also generated in many other manufacturing or power plants, and their properties and safe disposal requirements have generally been established. Wastes in this category will not be considered further in this study.

The residue material left after the extraction of the value metals from the raw nodules would obviously be unique to nodule processing. Examples of this type of waste,

generically called "rejects," include the leached tails from three-metal processes with or without subsequent manganese recovery, slags from a smelting process as well as residues from leaching sulfide mattes, and leached tails and fused salts from a reduction/hydrochloric acid leach process. Since only 2-3% of the weight of the raw nodules is recovered as products in three-metal plants, and 25-30% in four-metal plants, the weight of these rejects will approach that of the raw nodules processed. The properties of these materials will be the focus of this study.

Nodule processing plants will also produce a third type of waste which, while generally known from processing analogous terrestrial ores or other manufacturing operations, may have chemical or physical properties strongly influenced by virtue of its genesis in a nodule processing plant. Examples of this type of waste include tank house slimes (124), dusts from smelting operations, "crud" removed from liquid ion exchange reagents (329), and sludges produced from lime boil steps. While these types of waste are generated--and coped with--as an accepted result of existing processes, it may be necessary to consider special treatment or disposal methods for them if nodule processing results in the generation of unusually large amounts or if they contain significant amounts of toxic elements that would be released if normal disposal methods were used.

A comparison of the amounts of these types of waste produced by nodule processes and other manufacturing processes is summarized in table 2. Broadly, the amounts and types of waste produced from nodule manufacturing support operations are comparable to those from other processes, and the amounts of leached tails and slags are similar to those produced in the extractive metallurgy of terrestrial ores. Of the third type of waste, only the lime boil solids from the sulfuric acid leach process are produced in sufficient amount to perhaps require special consideration in their treatment and disposal. All others would most likely be handled in the same fashion as those produced from the same operations in the treatment of terrestrial ores.

The comparisons cited are, with the exception of the reduction/hydrochloric acid leach process, for reasonably analogous operations. Since no commercial plants are in operation on terrestrial ores using a hydrochloric acid route, the characteristics of the wastes have been inferred from information published on laboratory and pilot-scale testing of acid ferric chloride leaching of copper concentrates. Some data are also available describing nitric acid-based leaching processes, which would produce on the order of 900 mtpd (1,000 tpd) of wastes from a 45,000-mtpy (50,000-tpy) copper production plant.

Finally, the amount of waste produced in a conventional milling operation has been included for reference purposes. This waste, produced in far larger quantities than nodule process wastes, consists of finely ground material with grain sizes less than 270 mesh. However, since it has not been subjected to chemical alterations, its physical and chemical properties--particularly stability--more closely resemble the starting material than will leached tails from a nodule process.

The amounts of each type of reject from the six likely processing options are summarized in table 3. The estimates of the amounts of wastes generated from three-metal processes with manganese recovery from tails are rough, since detailed process flow diagrams have not been developed for the recovery process.

TABLE 2. - Comparison between nodule processes and other manufacturing processes based on amounts and types of waste

Type of waste	Nodule process route ¹	Amount ²	Terrestrial process analog	Amount ²
Combustion ash.....	Sulfuric acid leach	120 (135)	500-Mw coal-fired power plant	225 (250)
Scrubber sludge ³	Reduction/ammonia leach	75 (80)	500-Mw coal-fired power plant	365 (400)
Lime boil solids ^{3,4} ..	Sulfuric acid leach	1,850 (2,000)	NAP	
Water softening sludge ³	CUPRION	9 (10)	500-Mw coal-fired power plant	20 (20)
Smelting slag.....	Smelting	5,240 (5,760)	250,000-tpy copper smelter	2,270 (2,500)
Smelting dusts.....	Smelting	0-580 ⁵ (0-640)	250,000-tpy copper smelter	25 (25)
Leached tails.....	Reduction/ammonia leach	7,950 (8,750)	50,000-tpy nickel laterites ⁶	11,350 (12,500)
Leached tails.....	Reduction/hydrochloric acid leach	725 (800)	50,000-tpy copper concentrates ⁷	450 (500)
Mill tailings.....	NAP		3,000-tpd copper concentrator	90,700 (100,000)

NAP, Not applicable.

¹Nodule processing rate is 1.1 million mtpy as mined for the reduction/hydrochloric acid process and 4 million mtpy as mined for all other processes.

²First number represents dry mtpd; second number (in parentheses) represents dry tpd.

³Waste in slurry form; amount of solid waste reported.

⁴Similar to scrubber sludge in properties. Other routes produce 45-180 mtpd.

⁵None produced if conditioned dusts can be completely reworked. Maximum assumes no rework. Rework of 90% is likely.

⁶From 1.2% ore by the CARON process.

⁷From 25% chalcopryite concentrates by ferric chloride leach processes.

TABLE 3. - Amounts of solid rejects from manganese nodule processing plants¹

Process ²	Waste type		
	Leached tails ³	Slag	Other
Reduction/ammonia leach.....	7,900 (8,700)		
CUPRION.....	10,200 (11,200)		
Sulfuric acid leach.....	10,300 (11,300)		⁴ 2,000 (2,200)
Smelting.....	⁵ 70 (80)	5,700 (6,300)	⁶ 600 (700)
Reduction/hydrochloric acid leach.....	700 (800)		⁷ 600 (700)
Three-metal less manganese ⁸ ..	7300 (8,000)	970 (1,100)	

¹ Amounts are shown in dry mtpd; dry tpd are in parentheses.

² Nodule processing rate is 1.1 million mtpy as mined for the reduction/hydrochloric acid process and 4 million mtpy as mined for all other processes.

³ Rejects in slurry form.

⁴ Lime boil solids.

⁵ Residues from matte leaching.

⁶ Dusts. Maximum amount is for no rework; likely amount is 50 mtpd.

⁷ Fused salts.

⁸ Estimated, based on 50% recovery of manganese in tailings.

Development of a Classification Scheme for Process Wastes

It is desirable to group, in a suitable manner, the types of reject that would be produced from the various processing options to reduce the matrix of site/process/disposal technique combinations that must be evaluated to determine potential impacts. The data in table 3 from previous studies (96) suggest a classification based on amounts and types of waste.

It is known from the processing of terrestrial ores--specifically, nickeliferous laterites and copper or nickel sulfides--that the characteristics of rejects from hydro-metallurgical and pyrometallurgical processes will be significantly different. The residues from three-metal hydrometallurgical processes--leached tails--or residues from leaching steps in other processes consist of finely divided material that is not free draining and will settle to relatively stable, compressed pulps, which may still contain in excess of 30% moisture. Slags, however, are relatively coarse and drain freely, and are vitreous and generally considered to be inert.

While these types of nodule waste have reasonably close analogs from laterite processing operations, it is more difficult to characterize the rejects from a reduction/hydrochloric acid leach process. Based on extractive metallurgy, the closest analogs are

probably tails produced from the acid ferric chloride leaching of copper sulfide concentrates (196). These have been produced on a small scale commercially and are known to consist of large amounts of hydrous slimes that are difficult to settle and stabilize. This characteristic may not be unique to chloride leach processes, but may also be present for processes based on reductive leaching with sulfur dioxide or nitric acid, which essentially dissolve the nodule matrix almost completely. Any such process will produce the smaller amount of tails shown for the reduction/hydrochloric acid leach process in table 3. While fused salts will only be produced if fused salt electrolysis is used to produce electrolytic manganese, some other form of waste will be produced, in comparable amounts, in the manganese reduction step.

Thus, clear distinctions based on production rates and salient physical properties can be made between leached tails produced from three- and four-metal hydrometallurgical processes and between these materials and smelting slags. While the bulk chemical compositions, production rates, and physical properties are somewhat different for each process, there is little basis to develop a separate class of waste for any of the three-metal hydrometallurgical processes. A subclass might be developed, however, to represent the wastes produced from three-metal processes with manganese recovery from leached tails, since the amount of tails ultimately disposed of will decrease somewhat and significant amounts of another type of waste--slag--will be produced.

The gypsum sludge produced from the lime boil step in the sulfuric acid process will have physical properties, particularly grain size distribution and settled density, that resemble those of the leached tails of the process. Thus, while its bulk chemical composition will be quite different, it could be combined with tails for disposal if desired and would not constitute a separate class of waste. Since the amounts of both leach residues and dust produced in the smelting process are relatively small, and the residues and dust have chemical and physical properties similar to those produced in other extractive metallurgical processes, they might be considered manufacturing wastes treated by known techniques and would not constitute a separate class of waste.

In summary, the rejects from manganese nodule processing can be grouped into three major classes with one subclass:

- o leached tails from three-metal hydrometallurgical processes and lime boil solids if produced
 - residues from these processes from which some manganese has been removed by physical separation techniques
- o slags from smelting processes and from silico- or ferromanganese produced from manganese recovered from tailings (and from electrolytic manganese production, if appropriate)
- o leached tails from four-metal hydrometallurgical processes and residues produced from electrolytic manganese reduction steps (if not slags).

The characteristics of each of these types of waste that influence the method chosen for their further treatment, disposal, and reclamation are described in the following sections.

CHARACTERIZATION OF NODULE REJECTS

Physical and Chemical Properties Important in Waste Disposal

Since a variety of types of waste are generated and disposed of in the processing of terrestrial ores, there is a well-developed body of empirical data useful in the design of waste containment areas. However, in locations where environmental concerns have not been a high priority, little attention has been paid to the need to isolate wastes carefully, and the main information requirements have been the hydraulic and mechanical or structural properties necessary for the design of transportation systems and embankment structures. More data on the chemical and physical properties of wastes will be required to determine the type and detailed design of the impoundments required for nodule rejects. At present, it is necessary to rely on analogies to the properties of rejects from terrestrial ores whose characteristics are believed to be similar.

Three major types of information on waste properties influence the design of a containment system: chemical composition, index properties, and geotechnical properties. The chemical analysis of the solids and liquids should be complete, including both major and trace elements, and a mineralogical analysis of the solids to identify the phases that are present. The latter information will supplement data on the solids' ion exchange capacity and chemical stability, usually obtained in short-term tests, and help address the issue of the long-term potential for release of toxic elements by slow dissolution. The pH and buffering capacity of the liquids attending solid waste are also important in assessing the possibility of long-term solids dissolution as well as the suitability of various reclamation techniques in the short term. The amount of solid waste, its specific gravity, and its bulk density determine the volume requirements for the containment area, and its permeability determines the rate at which liquids will seep through. The other index properties (grain size distribution and Atterberg limits) and geotechnical properties (consolidation rate, shear strength, and compaction) are important in determining which reclamation techniques might be used and whether a portion of the waste itself might be suitable for use as a construction material for the containment area.

Much of this information has been obtained for mining and milling wastes that are generated in large amounts in the United States and throughout the world and are not considered difficult to dispose of (450). The emphasis has usually been on the improved mechanical design of rather simple containment areas. For wastes which are difficult to dispose of, such as the leached tails resulting from aluminum extraction from bauxite--so-called red muds--more information is usually sought on chemical properties (367). Since physical and chemical properties of rejects arising from different metallurgical processes differ greatly, it is necessary to draw analogies very carefully when attempting to estimate the properties of wastes that have not been produced in quantity.

Properties of Rejects from the Processing of Nickeliferous Laterites

Based on both the mineralogy of the raw materials and the extractive metallurgy involved, it is logical to draw analogies to the properties of rejects from laterite processing in estimating the properties of nodule rejects. However, nodule rejects produced by a reduction/hydrochloric acid leach process--or other four-metal hydro-

metallurgical processes--do not have direct analogs in laterite processing, and other sources must be sought.

Laterites are iron-based oxide ores containing, typically, 1-2% of nickel oxides, which are so distributed in the mineral matrix that they cannot be separated and concentrated by physical means. The ores also contain significant and varying amounts of the oxides of aluminum, chromium, magnesium, and silicon, and lesser amounts of other elements. Nickel and cobalt are recovered after reduction of the oxide matrix of the ores by either hydrometallurgical or pyrometallurgical processes. Indeed, this extractive metallurgy was the basis for much of the early development work on nodule processing.

The composition and chemistry of laterite smelting slags from a variety of processes is well documented (73, 243). Nodule processing slags would contain comparable amounts of iron oxides and silica, but the high magnesium oxide content would be replaced by manganese oxide. However, since the liquid melting points, densities, and viscosities should be similar, the physical properties of the granulated slags should be comparable, and their vitreous structures should be similar as well. While it is known that disposal of laterite slags does not present unusual problems, it does not appear that data on their index or geotechnical properties have been made available.

Data on the composition of leached tails from laterite processing can be developed from reports of plant performance and a knowledge of the composition of the raw materials (339). However, this does not provide information on the chemical stability of the rejects or other physical properties. It is known, however, that they are finer than the raw material, which is ground to 85% below 200 mesh (70), or 60% below 325 mesh (339) prior to reduction. The tailings from the latter plant show thickener underflow densities that are the same as those expected in a nodule processing plant are transported to the disposal area as a slurry at 50% solids and are ultimately impounded, behind dams sealed with compacted clays, in large (85 ha each) tailings ponds. They have been successfully reclaimed by simple revegetation directly on the surface of the reject material. However, it is not usually possible to use laterite rejects themselves as a structural material in the construction of a containment area (182). Unfortunately, no data are available on other index or geotechnical properties of this material.

Properties of Rejects from Manganese Nodule Processing

Since no commercial-scale nodule processing plants have been built, and pilot-scale plants have been operated for relatively short periods of time, little reject material is available that can be considered representative of the rejects commercial plants would produce. Based on pilot-scale tests of its CUPRION process, Kennecott has information on the particle size distribution and settled density of reject material. This information comes from a pilot plant operating 20 days continuously. For other processes few data have been published on the properties of the wastes that have been generated, so it is necessary to rely on the results of material balance calculations to estimate the composition of the rejects and analogies to laterites for index and geotechnical properties.

The bulk chemical composition of both solid and liquid wastes has been calculated for likely first generation process plants (96), and the main constituents of the solid phases are summarized in table 4. The assignments of chemical species to the elements, where indicated, were based on considerations of the general chemistry of the process and not on direct observation. The term "clays" refers to a complex mixture of fine-

TABLE 4. - Major constituents in rejects from nodule processing

Element	Reduction/ ammonia leach	CUPRION/ ammonia leach	Sulfuric acid leach
Manganese.....	MnO MnO ₂ MnCO ₃	MnCO ₃ MnO ₂ MnO	MnO ₂ MnO
Iron.....	Fe(OH) ₂ FeCO ₃ FeOOH	Fe(OH) ₂ FeCO ₃ FeOOH	Fe ₂ O ₃ Jarosites
Na, K, } Ca, Mg, } Clays.. Al, Si }	Nearly unaltered	Unaltered	Altered with formation of sulfates
	Smelting	Reduction/ hydrochloric acid leach	
Manganese.....	Mn MnO	MnO ₂ in tails MnCl ₂ in salts	
Iron.....	FeO Fe	Fe(OH) ₃ FeOOH	
Na, K, } Ca, Mg, } Clays.. Al, Si }	Oxides in slags	Al, Si oxides in tails. Others as chlorides in salts.	

grained mineral species, which are largely hydrated alkali and alkali earth silicates. Confirmation of these estimates would provide valuable insights in the prediction of the long-term chemical stability of the rejects. For example, potentially toxic elements associated with the "clay" phase of raw nodules--which are generally considered inert--would be expected to remain immobilized in the rejects from the ammonia leach processes, since the clays are essentially unaltered in the process. Similarly, they would be expected to remain immobile in the vitreous matrix of smelting slags, but would be dissolved and enter the process if soluble in acid sulfate or chloride solutions.

The solutions in process throughout the plant contain varying amounts of reagents, dissolved metals, dissolved sea salts, and other trace elements. The great majority--over 98%--of the dissolved metals and reagents are removed in washing and recovery steps and are removed as product or recycled. Since the composition, temperature, and pH of the solutions are changed throughout the process, some of the dissolved trace elements may be either incorporated with process wastes or co-reduced and sold with the value

metals, or they may exit the process with the rejects stream. All rejects will, at a minimum, be treated to adjust their pH, probably into the range 6-9, and this will result in the precipitation of most of the heavy metals and some trace elements as hydrated oxides. With the exception of the smelting process, liquids accompanying the leached tailings will contain dissolved sea salts, and other soluble salts formed in processing, at concentrations up to a few percent. In the smelting process, these salts will have been either incorporated into the slag or fumed off, with other volatile reduced elements, and collected in the smelter dusts.

The raw nodules contain small amounts of elements usually considered toxic in some form, although they are tightly bound in a stable matrix before processing. The trace element content is highly variable (236), and not all compounds formed from these elements will be considered toxic, for example, barium sulfate from the sulfuric acid leach process. However, elements of interest because of their potential toxicity include those mentioned as priority pollutants under the Toxic Substances Control Act (TSCA), those listed in EPA and U.S. Public Health Service (PHS) drinking water standards, and those mentioned in other sources of information on the properties of hazardous materials. EPA has developed an extraction procedure to determine the toxicity of solid wastes--the EP Toxicity Test--and lists elements that, if present in sufficient concentration, will result in classifying the waste as hazardous under the toxicity definition. Based on these considerations, it is essential to determine the fate of the following elements in an integrated nodule process: cobalt, nickel, copper, manganese, molybdenum, and zinc (the value metals); and arsenic, antimony, barium, cadmium, chromium, lanthanum, lead, selenium, thallium, and vanadium. While also considered toxic, the concentrations of beryllium, mercury, and silver are so low in raw nodules that they are unlikely to be concentrated in any waste stream sufficiently to represent a potential hazard.

The majority of the copper, nickel, and cobalt are recovered in the process plant. Molybdenum and zinc have been included since they are marketable metals which may be recovered if desired by well-developed technology. The process rejects will contain most of the unrecovered value metals (approximately 10% for copper and nickel, 50% for cobalt, and 100% for molybdenum and zinc for the processes in figures 1-5) probably in the same form as in the raw nodules. The rejects will also contain up to 2% of the dissolved value metals, which are precipitated after passing through tailings washing steps. The distribution of other potentially toxic elements among products, rejects, and other wastes has been calculated (96) and is summarized in table 5. As with the estimate of major constituents, these distributions have not been supported by direct observation in most cases, and the species present and their stabilities are not known. This information must be available if use of rejects for land fill or soil extender is to be considered seriously.

Very little information is available on the index or geotechnical properties of nodule rejects. It is possible to estimate the specific gravity of the solid phase based on the density of the constituents assumed to be present, and the void volume could be estimated if the grain size distribution were known. It has been reported (181) that rejects from a hydrometallurgical process will be fine grained--generally below 250-350 mesh--and should therefore resemble laterite tailings. It has also been reported that rejects from a hydrometallurgical process settle rapidly to relatively high densities, which is also characteristic of laterite tailings (339). The U.S. Bureau of Mines has recently carried out some preliminary testing to determine the properties of rejects produced in small-scale process development tests for the CUPRION process (403). The material was found to be fine grained (100% minus 200 mesh), had relatively low permeability and retained significant amounts of moisture upon settling. Other

characteristics will have to be estimated by analogy until such time as test data become available.

The estimates in table 5 show that potentially toxic elements will be dispersed in a variety of wastes produced in nodule processing plants. In addition, certain types of manufacturing waste, such as sludges from stack gas scrubbers, may contain toxic elements introduced from other sources such as coal used for steam generation. The types of manufacturing waste that will contain potentially toxic elements derived from the nodules themselves are tank house slimes, ion exchange section crud, spent carbon from nickel electrolyte purification, lime boil solids, dusts scrubbed from process vents (if not recycled), solids from pH adjustment steps, and smelter dusts. No information is available on the physical and chemical properties of the specific types of materials that would be produced in a nodule processing plant. It is possible that smelter dusts could be produced in large quantities if it became necessary to control the buildup of objectionable elements in the products by purging them through the dusts. Otherwise the amounts of these wastes will be relatively small, and there is no reason to believe that they cannot be disposed of in an acceptable manner using well-established techniques. However, a separate disposal area(s) may be required for these materials, and some attention should be paid to defining their properties and proper treatment and disposal techniques. This effort is outside the scope of the present study.

Classification of Nodule Rejects for Disposal

In the previous sections, available information on the physical and chemical properties of rejects from nodule and laterite processing has been summarized. In general, very little data have been published on the types of information that are important in determining how these rejects should be classified and, therefore, how proper containment areas will have to be designed. A key question for each class of rejects--three-metal leached tails, slags, and four-metal leached tails--is: Should the material be considered hazardous?

The waste characteristics defined in the Resource Conservation and Recovery Act (RCRA) that are relevant to the classification of solid waste as hazardous are EP toxicity (acetic acid extraction), corrosivity, radioactivity, and presence of cyanide. The last two are not of concern for rejects from processing nodules: the nodules contain negligible amounts of radioactive substances and cyanides are not used in their extractive metallurgy. Corrosivity, defined as a characteristic of streams having pH less than 2 or more than 12.5, is of little concern either. The nodule rejects will be treated to maintain a near neutral pH. The rejects will be considered hazardous by virtue of their toxicity, however, if any of the EP toxicity contaminants are leachable in the standard test to concentrations that exceed limits established by EPA. It has been reported in preliminary surveys that certain samples of mining and milling wastes are hazardous by this criterion (320). While none of the wastes tested are mineralogically similar to nodule rejects and none of the samples tested showed EP toxicity when extracted with water, all contained the potentially toxic elements expected to be present in nodule rejects at comparable concentrations.

In the absence of data to the contrary, then, it is reasonable to assume that the rejects from three-metal hydrometallurgical processes may show the characteristic of toxicity by this criterion. The well known sorptive capacity of manganic oxides for heavy metals (238) will probably not be sufficient to reduce their activity in solutions at the pH of the test (18). This conclusion would also apply to rejects from four-metal hydrometallurgical processes and particularly fused salts, which are highly soluble. In a

TABLE 5. - Estimated distribution of trace elements in manganese nodule processes¹

Compounds of	Reduction/ammonia leach and CUPRION/ammonia leach				High temperature sulfuric acid leach			
	Products ²	Rejects ³		Other wastes	Products ²	Rejects ⁵		Other wastes
		(%)	(ppm) ⁴			(%)	(ppm) ⁴	
Antimony....	1.3	90	32	8.7	7.3	43	12	49.7
Arsenic.....	4.9	50	29	45.1	-	10	5	90
Barium.....	-	100	4,650	-	-	100	3,600	-
Cadmium.....	5.3	10	2	84.7	37	-	-	63
Chromium.....	0.1	90	11	9.9	0.3	90	9	9.7
Lanthanum...	-	90	1,670	10	-	50	721	-
Lead.....	1.2	90	528	8.8	-	90	409	10
Thallium....	15.7	10	23	74.3	7.6	50.6	91	-
Vanadium....	0.1	90	418	9.9	1.5	10.4	37	88.1
Smelting/ sulfuric acid leach					Reduction/ hydrochloric acid leach			
	Products ⁶	Rejects ⁷		Other wastes	Products ⁶	Rejects ⁸		Other wastes
		(%)	(ppm) ⁴			(%)	(ppm) ⁴	
Antimony....	0.7	-	-	99.3	20.2	10	17	69.8
Arsenic.....	-	10	8	90	9.9	10	11	80.1
Barium.....	-	100	6,470	-	-	100	14,160	-
Cadmium.....	51	45	15	4	1.4	-	-	98.6
Chromium....	45	55	9	-	0.5	90	34	9.5
Lanthanum...	-	100	2,610	-	-	100	5,710	-
Lead.....	50	45	358	5	0.1	90	1,565	9.9
Thallium....	50.5	45	146	4.5	3.9	50	354	46.1
Vanadium....	45	54	338	1	9.4	13.3	182	77.3

¹ Percent of element in raw nodules reporting to each stream.

² Copper, nickel, and cobalt.

³ Leached tails.

⁴ Estimates from other sources may vary by as much as an order of magnitude from these numbers.

⁵ Leached tails and lime boil solids.

⁶ Copper, nickel, cobalt, and manganese.

⁷ Slags.

⁸ Leached tails and fused salts.

freshwater system it is likely that these wastes would have to be disposed of in impervious containment areas if for no other reason than to prevent the seepage of sea salts into groundwater. However, if they are also found to be particularly susceptible to leaching under realistic conditions, as by prolonged contact with acid rain, an elaborate monitoring system may be required for the disposal area.

Extraction procedures that are intended to measure the potential toxicity of wastes by virtue of their susceptibility to releasing hazardous compounds have been developed using solvents other than acetic acid. An extraction procedure using seawater has been used to characterize the behavior of materials, such as dredge spoil, that are to be disposed of at sea. Recently, the American Society of Testing and Materials has published a standard procedure, ASTM D3987-81 (3), for the extraction of potentially toxic elements from solid waste materials using water as a solvent. Because nodule rejects will be in contact with water, not acetic acid, in the containment area, they should be subjected to the ASTM D3987-81 test or an equivalent. This procedure should provide a more realistic estimate of the stability of the wastes with respect to the leaching of potentially toxic elements in a containment area. It is quite likely that nodule rejects would not show the characteristics of toxicity by water extraction, even if the acetic acid extraction test were positive, as was the case for certain mining wastes that have been tested (320). Also, as pointed out by a study of the lixiviation of mine wastes for BuMines (12), a valid testing procedure should account for actual leaching conditions and regional precipitation chemistry, including pH.

Based on long experience with the inert behavior of smelting slags in a wide variety of environments, it may be presumed that slags from nodule smelting processes will not be considered hazardous. The toxic elements will be stabilized within the vitreous matrix and are not likely to be mobilized by an extraction in acetic acid. It will be necessary to site the disposal area for this material in a manner that is consistent with local land use requirements and according to normal practice in the disposal of slags.

The amounts of each major class of waste that must be disposed of, their key physical properties, and the terrestrial analogs on which these estimates are based are summarized in table 6. In assessing the environmental considerations attending the disposal of rejects from nodule processing plants, both the chemical composition and stability of the reject material itself, as well as the site, size, and structure of the containment area, will be considered. Viewed strictly from the perspective of minimizing waste disposal problems, a smelting process would be preferred. While containment and reclamation of rejects from three-metal hydrometallurgical processes should not present unique disposal problems, the area requirements will be large. More care will be required in the design and monitoring of a containment area for rejects from four-metal hydrometallurgical processes, but the smallest volume of waste will be produced in these processes.

These conclusions are all based on analogies to the properties of rejects from the processing of similar terrestrial ores. Experimental data on the properties of rejects made during the operation of pilot plants will be required to support the permitting activities necessary for plant and waste disposal facility siting.

TABLE 6. - Characteristics of rejects from manganese nodule processing plants

Class of rejects ¹	Amount of dry waste ²	Estimated particle size distribution, 100% passing	Estimated percent solids by weight (settled)	Settled volume ³	Stability ⁴	Terrestrial analog
Three-metal hydrometallurgical process tails.....	3.2 (3.5)	200 mesh	50-60%	2.7 (3.6)	Good-excellent (Fair-poor)	Nicarao and Moa Bay, Cuba
Four-metal hydrometallurgical process Tails..... Salts.....	0.24 (0.26) 0.21 (0.23)	400 mesh Massive	50-60% 80+%	0.3 (0.4) 0.15 (0.2)	Fair-poor (Poor)	Duval-Sierriita, Arizona
Smelting slag.....	1.9 (2.1)	10 mesh	80+%	0.75 (1.0)	Poor (Excellent)	Dominicana, Dominican Republic
Three-metal process less manganese Tails..... Slag.....	2.4 (2.6) 0.32 (0.35)	325 mesh 10 mesh	60-70% 80+%	2.4 (3.2) 0.15 (0.2)	Good-excellent (Fair-poor)	None direct, but as above

¹ Nodule processing rate is 1.1 million mtpy as mined for four-metal hydrometallurgical processes, 4 million mtpy as mined for other classes of rejects.

² Million mtpy. Values in parentheses are million tpy. Tailings are in slurry form.

³ Million cu m/year based on mean percent solids. Million cu yd/year in parentheses.

⁴ Stability with respect to reclamation by conventional practice. First rating is for revegetation. Second rating (in parentheses) is for structural stability.

WASTE DISPOSAL TECHNIQUES

Background

Prior to the past 10 years, waste disposal has been given relatively little consideration by the mining industry. Generally, the methods used have been whatever was least expensive, often without regard for environmental consequences. As a result, the mining industry has recently come under scrutiny by various State and Federal agencies. State health departments and the engineer's offices are usually involved in reviewing the design of new mine tailings disposal facilities. At the Federal level, EPA, the Nuclear Regulatory Commission (NRC) (only in the case of uranium tailings disposal facilities), and the Mine Safety and Health Administration (MSHA) are the primary agencies regulating tailings disposal. MSHA does not have a direct role in regulating tailings that are not produced from terrestrial mines. BuMines has taken an active role in the technical aspects of tailings disposal, but has no regulatory role.

As a result of State and Federal involvement, the state-of-the-practice regarding construction of waste disposal facilities has improved significantly. Present State and Federal guidelines outline certain characteristics that an ideal disposal site should possess. These characteristics are described below.

- o Surface water - The site should be located outside of surface drainage paths or at the head of a drainage.
- o Groundwater - Groundwater should be located well below the disposal level of the waste.
- o Geology - The soil and rock below the disposal site should be low in permeability and stable. The site should be in a region with little or no seismic activity. The site should also contain sufficient borrow material for construction of seepage barriers and dikes and for reclamation.
- o Environment - The waste disposal activities should have minimal impact on flora and fauna, cultural resources, water quality and quantity, and air, noise, and visual pollution adjacent to the site.

Types of Waste

There are two general types of waste streams anticipated from the processing of manganese nodules, a dry vitreous slag from pyrometallurgical processes and a fine-grained slurry from hydrometallurgical processes. The smelter slag waste will be easier to dispose of because it is expected to be

- o chemically inert,
- o relatively dense,
- o high in shear strength (that is, physically stable and useful for construction),
- o valuable for secondary uses (such as structural fill, road base), and
- o non-dust generating.

Because of these properties the slag can be disposed of in either a wet or dry climate using conventional landfilling practices. Leachate should not be a problem due to the inertness of the waste. Likewise stability and handling are enhanced by its high strength and density and dryness. Reclamation would involve contouring to suit the local topography and placement of a soil cover for revegetation.

The slurries from the hydrometallurgical processes probably will consist of a fine-grained material having the following characteristics:

- o primarily silt and clay size particles,
- o not chemically inert (possibly toxic by EPA toxicity standards),
- o low shear strength (cannot be used for retention structure construction),
- o high moisture content, and
- o compressible and difficult to reclaim.

Because of these properties the slurries will require containment in engineered disposal facilities. Because of its low strength an impounding structure or below-grade (pit) disposal method will be necessary. Since the slurry probably will not contain sufficient sand size particles for efficient cycloning, these retention structures will have to be built entirely from borrow materials. Depending on its chemical composition, lined pits or special treatment to neutralize the slurry may be required. In addition, dewatering by means of evaporation and/or the use of underdrains will be necessary prior to reclamation. Overall, disposal of the slurry wastes will be more expensive and will require more sophisticated technology than will disposal of slag.

Description of Available and Emerging Techniques Relevant to Nodule Rejects

Slag Disposal

Because of its favorable physical and chemical properties, slag can be disposed of in a wet or dry climate equally well using conventional means as described below.

Landfilling

Slag can be disposed of in an operation similar to that of building a mine overburden waste dump or a "heaped embankment" (89). The site preparation would begin by stripping and stockpiling soil for final cover. Slag would be transported to the disposal areas by conveyors, trucks, trains, or scrapers. A key design element for this disposal system is that no water would be impounded. The top would be crowned to shed water. Exterior slopes would be graded to blend with natural features and would probably range between 3H:1V and 5H:1V. Once design heights are reached the waste would be covered with soil and revegetated. Because of the inherently stable character of the slag, fugitive dust, surface erosion, and catastrophic failures would not be problems.

Preferred sites would be located outside of surface water courses to minimize the amount of water that would have to be diverted. Because of the inert chemical

character of the slags, leachate control would not be a problem; therefore, the subsurface geology is not critical.

The final land use for sites filled with slag will depend on how the slag was placed. Due to its high shear strength and inert nature, slag placement can be controlled such that a uniform high density is achieved. Therefore, the disposal area can be used for commercial or industrial development or agricultural purposes after disposal is complete.

Beneficial Uses

Slag has been marketed commercially for use as structural fill, roofing gravel, decorative rock, breakwater dikes, road base, and sand for ice and snow traction. A prime example of exploitation of this slag material is at the American Smelting and Refining Co. (ASARCO) smelter in Tacoma, Washington (459). The slag is used locally and as far away as British Columbia. In this instance the demand actually exceeds the supply. The possibility of finding beneficial uses for the slag is probably good at all of the mainland sites and could preclude most of the disposal problem.

Slurry Disposal

Because of the potentially toxic nature and low strength of the slurry wastes, a more sophisticated disposal system is required to assure containment of the waste. There are a number of alternative designs that have been used and proposed for similar wastes. These designs, which are discussed below, include cross-valley dam, fully enclosed impoundment, specially excavated pit, "dewatered" tailings in a landfill, backfilling surface mines, deep disposal, and liquid disposal.

Cross-valley Dam

To provide for waste containment a starter dam is constructed from borrow soils. Sites should be located at the head of a drainage in a manner that minimizes the volume of water that must be diverted around the site, maximizes storage capacity, and reduces the volume of borrow needed for the dam.

The waste is disposed of in the reservoir created by the dam and is typically discharged from the upstream face of the dam through a series of spigots. As waste is discharged and settles, a pond typically forms from the excess moisture in the waste. This liquor is collected by a decant system and returned to the process plant for reuse. Particularly in wet climates it is often necessary to treat and discharge excess water.

Depending on the properties of the waste and the permeability of the soil or rock on which the waste is disposed, a natural or synthetic liner may be necessary to control seepage (395). Figure 6 shows a schematic cross section of an unlined cross-valley dam. These dams can be raised by several methods (449), which are shown in figure 7. However, because of the fineness of the tailings, it is likely that only the centertine or downstream methods utilizing borrow materials for raise construction could be used. The upstream method requires little or no borrow material and is used by the mining industry because tailings usually contain enough sand in the 60 to 200 mesh sizes to build dikes. The nodule tailings are unlikely to meet this requirement.

Regardless of the disposal system used, reclamation of the slurry wastes is of considerable concern due to their high moisture and low strength. To reclaim areas filled with slurry wastes, ongoing stabilization of the wastes is required so that they have

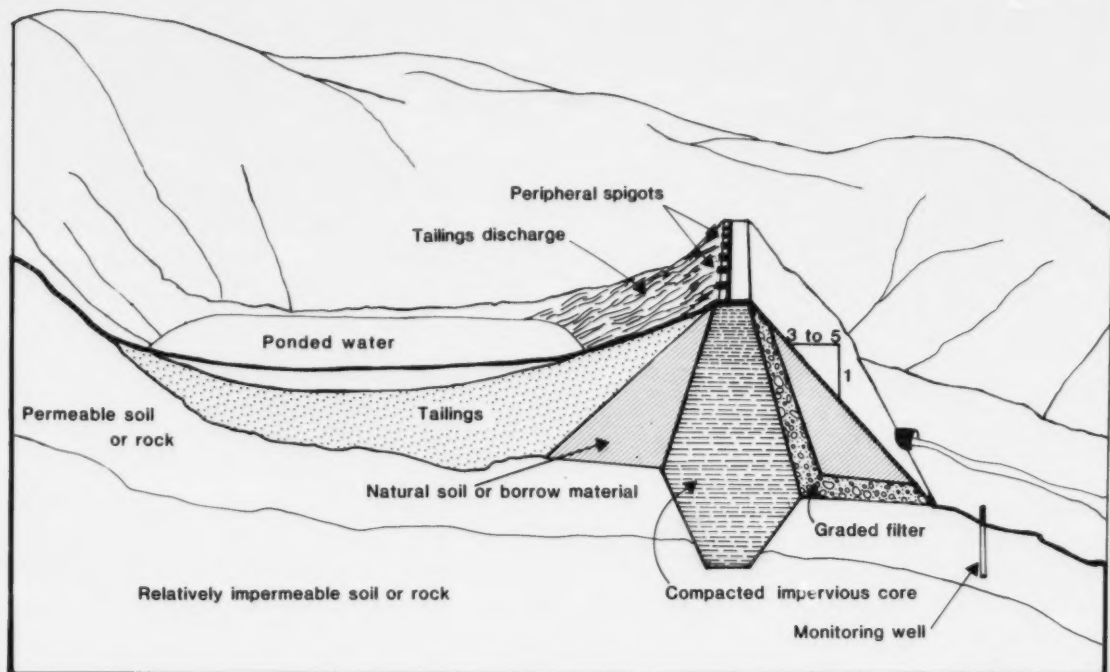


FIGURE 6. - Schematic cross section of an unlined cross-valley dam.

adequate strength to support reclamation equipment and will not settle significantly following reclamation. In wet climates stabilization of the wastes is enhanced by underdrain systems and pumping off the liquor that forms on the surface. In dry climates evaporation accelerates the stabilization process.

The potential for release of tailings and effluent from a cross-valley retaining structure exists but is not great for a properly managed system. Fugitive dust blowing off the tailings surface is a common chronic problem, particularly in dry climates, although this problem does not lead to catastrophic releases. Control measures such as chemical treatments, wetting the surface, and covering the surface with gravel or similar materials are available.

Similarly, seepage can be a chronic problem that can be controlled by seepage barriers or by intercepting the seepage.

The major concern for catastrophic release would be failure of the retention structure, a possibility that exists with any dam. However, for properly engineered dams constructed from borrow materials, the likelihood of this happening is extremely small.

An example of a project where a cross-valley dam raised by the downstream method has been used is Homestake Mining Company's Grizzly Gulch tailings dam for its Lead Gold Mine, Lead, South Dakota (173).

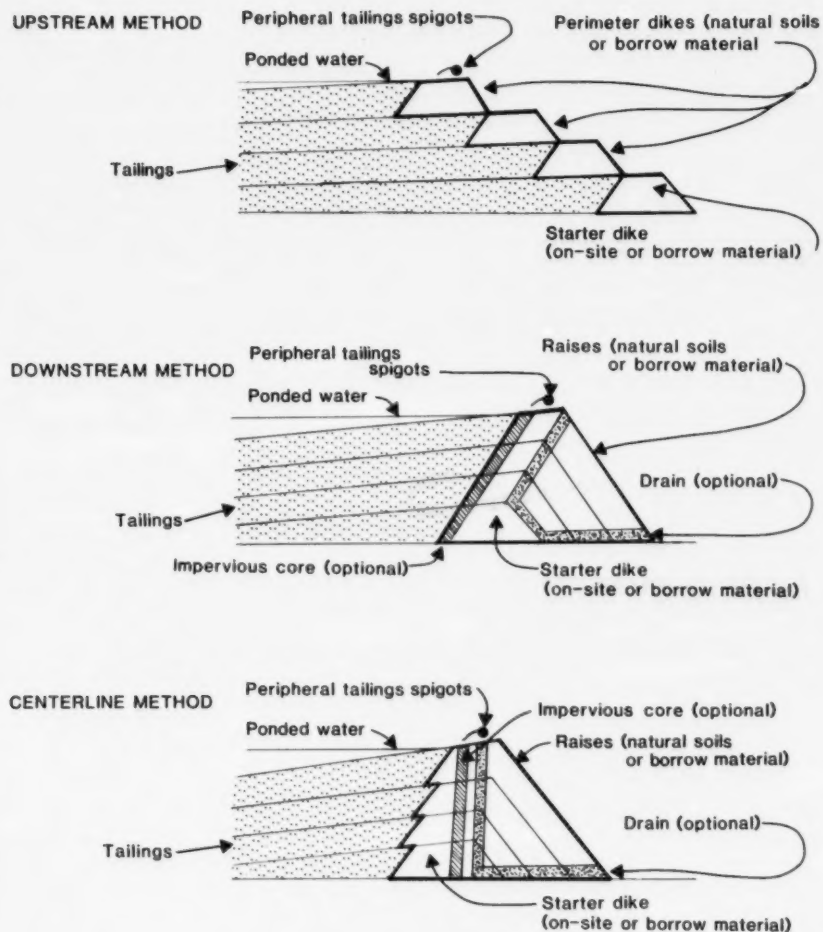


FIGURE 7. - Methods of dam construction for tailings impoundments.

Fully Enclosed Impoundment

This type of design consists of a ring (four-sided) dike or, in steeper topography, a three-sided side hill dike which contains the waste. This design is typically used where the topography is not favorable for construction of a cross-valley dam, and sufficient borrow material is available for dike construction.

This design has constraints similar to that of the cross-valley dam. The primary concerns are the availability of borrow soils, low permeability bedrock or soil underlying the disposal area, ample room, and location away from major drainages.

Like cross-valley dams, the dikes can be raised in stages and borrow materials must be used since the tailings are not suitable. The potential for fugitive dust, seepage, and catastrophic failure exists to essentially the same extent as described for cross-valley dams except that more embankment is usually involved. The same control measures are effective also.

Reclamation concerns are similar to cross-valley dams. However, as illustrated on figure 8, by dividing the disposal area into cells the reclamation can be staged so that only a small area at any one time is actively being used for disposal (80). Cells typically are sized to receive 2-5 years of tailings.

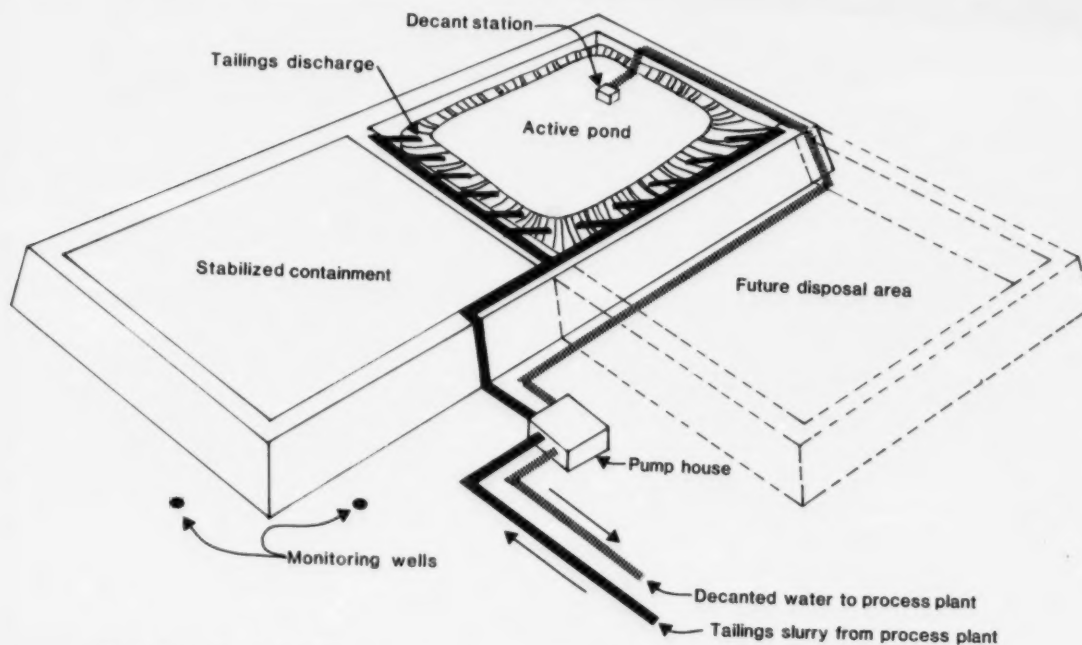


FIGURE 8. - A fully enclosed tailings impoundment divided into cells.

Reclamation concerns beyond waste stabilization include long-term control of wind and water erosion, since these above-grade impoundments are not sheltered by topography as are below-grade and partially below-grade containments.

Examples of this technology are prevalent in phosphate mining in Florida, where slurry wastes must be disposed of in relatively flat topography (35).

Specially Excavated Pit

This method consists of excavating a pit or trenches specifically for disposal of the tailings. If necessary the pit can be lined to control seepage. This type of system is used where long-term containment of the waste is of primary concern or where other methods are not feasible. Groundwater should be well below the base of the pit. Waste stabilization is typically carried out using underdrains to dewater the tailings.

The principle advantages of this method, which normally is more expensive to construct than surface facilities, are as follows:

- o The likelihood of catastrophic releases is negligible because of below-grade disposal.

- o Wind erosion is a minor problem.
- o Long-term stability is excellent. Since tailings are below grade, erosion is unlikely.
- o Visual impacts are minimal both during operation and after reclamation.

This method is currently in use at several uranium tailings disposal facilities (361, 432).

Dewatered Tailings in a Landfill

This method is for tailings which are "dewatered" (that is, they have free water removed) prior to disposal. The dewatering is usually accomplished by belt filtration or centrifuging. This provides a tailings material with no excess moisture, and hence will not provide moisture for migration of effluent. Other benefits are higher density (which leads to smaller storage volumes), greater stability, and easier reclamation. The main disadvantage of dewatering is the high cost for the dewatering step. Also, not all tailings, especially those with a high clay content or fine particle size, can be successfully dewatered by mechanical techniques. The dewatering can be accomplished at the plant or at the disposal area. Where the tailings are dewatered at the plant, they are conveyed or trucked to the disposal area. At the site, cells are prepared to receive the waste, and periodically the waste is covered to prevent wind and water erosion and to reduce infiltration. A final cover is placed over completed areas and is revegetated. Since the tailings are stable, reclamation can occur immediately after placement.

The actual disposal system can resemble a cut-and-cover landfill operation. Typically in this system, trenches are excavated as storage area is needed. In this way a semi-continuous excavation/disposal/reclamation plan can be achieved. This scheme minimizes the high initial costs associated with most tailings disposal systems.

Once processed, the material can be placed in a cut-and-fill operation, similar to the landfill previously described for slag. Problems of effluent seepage are minimal because there is no free water; nevertheless, particularly in wet climates, low permeable soils/bedrock should be below the site and placed over the tailings. Typically the costs of drying the wastes are balanced against requiring a liner.

Pioneer Uranium, Inc., plans to use this technology at its San Miguel project in southwestern Colorado (456).

Backfilling Surface Mines

This design is the same as the specially excavated pit discussed above except that the pit consists of an existing or abandoned mine or quarry. Special design features include backfilling the pit to above the water table before placing tailings and lining the bottom and sides of the pit. The advantages of this method are the same as for specially excavated pits, but the cost probably would be less if a mine or quarry were close to the process plant. A typical schematic is shown in figure 9.

This method will be used by United Nuclear Corporation at its Morton Ranch Uranium Mill in Wyoming (361).

Deep Disposal

This method involves waste disposal in underground mines or caverns. Assuming that the tailings will be toxic, the main concerns regarding use of this method are

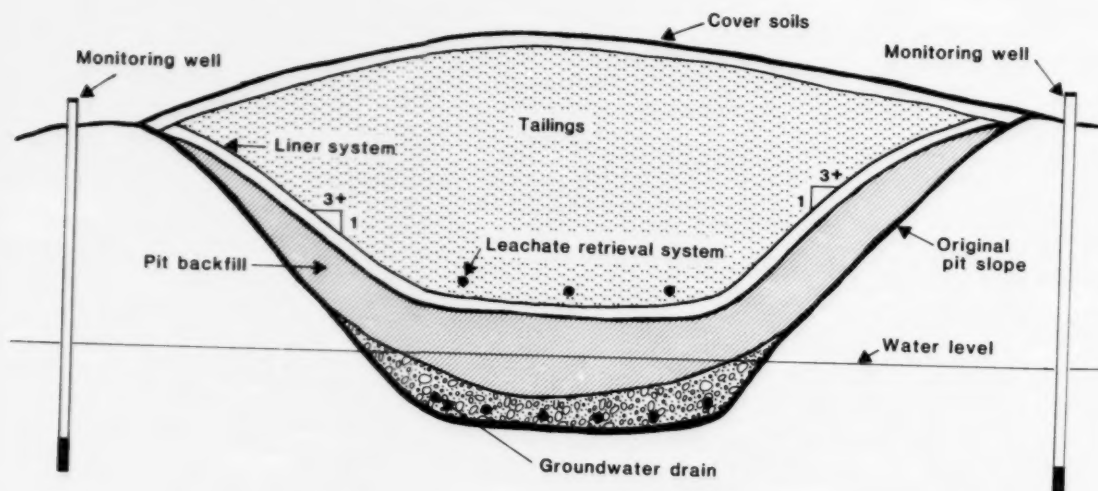


FIGURE 9. - Tailings disposal by backfilling a surface mine.

protection of aquifers and the stability of the mine over the long term for waste containment.

Deep disposal is advantageous in that reclamation is not required and fugitive dust is not a problem. Catastrophic releases are possible and have happened. Furthermore, visual and socioeconomic impacts are minimal. The main limitation is unavailability of suitable deep mines of adequate size near port areas.

This method is currently being considered for industrial and chemical disposal in salt mines by the USGS (125).

Liquid Disposal

If slurry wastes were dewatered the remaining liquid wastes could be treated or disposed of through evaporation or deep well injection. Evaporation ponds are commonly used in the mineral processing industry to get rid of excess water or effluent. They involve construction of a lined pond large enough to handle effluent on a year-round basis, with sufficient volume to handle liquid accumulation during periods of low evaporation and/or high inflow and with enough area to evaporate all excess liquid. Essentially the same considerations as discussed above for a fully enclosed impoundment apply to evaporation ponds. Evaporation ponds normally are periodically cleaned to

remove solids, but the pond itself is usually removed prior to site reclamation, so that the long-term impacts of an evaporation pond are minimal.

Deep well injection requires a well to be drilled into a stable formation that would assure containment from any usable aquifers. Examples of operations where deep well injection has been used are at U.S. Industrial Chemicals Co., Douglas County, Illinois (approximately 5,300 feet deep) (461); and at in situ uranium mines in the South Texas Uranium Belt (377).

Waste Treatment Options and Their Effects on Disposal

The final treatment step in the nodule processing plant will probably involve the adjustment of the pH of the rejects stream to near neutral, that is, 6-9. This will decrease its corrosivity, precipitate most heavy metals or potentially toxic elements that have passed through previous washing steps, and provide a favorable medium for subsequent reclamation of the disposal area. Tailings from three- and four-metal hydrometallurgical processes will be transported to the disposal area in slurry form, while granulated slags may be transported either as slurries or dewatered at the plant and transported, drained, by conveyor, truck, barge, or rail. In certain areas, unfavorable climate or terrain at the disposal site may result in difficulty in managing the water balance. As a rule, the area requirements for the disposal site could be reduced and the mechanical properties of settled slurries improved if their water content could be reduced. Finally, if the permeability of the rejects is not relatively low and the soils in the area cannot be compacted to make them impervious, it may be necessary to install expensive liners to control seepage. Thus, a number of additional waste treatment options might be considered to improve the properties of the rejects.

In water short areas, net evaporation from tailings ponds should not present a problem. However, if the tailings slurries could be dewatered mechanically, a portion of the removed water could be recycled to the processing plant, decreasing the demand for makeup water there. In wet areas, dewatering would help alleviate the evaporation problem and permit the construction of smaller, deeper ponds. The data available on the properties of tailings from nodule processing suggest that they are quite fine grained, perhaps minus 200 to minus 400 mesh. For such fine material cycloning is not likely to be effective in dewatering since even separating hydrous slimes from the better drained fines would require many, very small cyclones. Techniques such as centrifuging or filtering would be required. While use of such equipment would be technically feasible, the costs would be quite high because of the large amounts of material that would have to be treated. A number of the largest machines of either type, operating in parallel, would be required. This would entail much more operator attention than normal for disposal areas as well as additional maintenance costs. For these reasons, tailings dewatering will probably not be considered except to mitigate an unusual disposal problem. It is not likely that slags will require additional dewatering under any circumstance.

Another waste treatment option that might be considered to improve the properties of tailings is chemical fixation. Addition of the proper types and amounts of pozzolanic reagents would not only improve index and geotechnical properties, but also increase chemical stability by providing a more stable matrix to prevent extraction of potentially toxic elements. As is the case for filtration, however, such an approach would be very costly and require large amounts of reagents because of the large volumes of tailings to be treated. Since available information suggests that these rejects can be contained in an acceptable manner in tailings ponds of conventional design, and since it

is not clear that use of a chemical fixation technique would either permit the use of a lower cost disposal option or mitigate an otherwise difficult disposal problem, it is not likely to be used. Chemical fixation would not be required for slags under any circumstance, but might be used to stabilize certain of the manufacturing wastes, which would be produced in much smaller quantities.

Reclamation and Availability for Further Processing

Slag Disposal

As discussed previously, the slag will most likely be disposed of by a landfill technique or used for other beneficial purposes. Until the present time, regulations have not required reclamation of slag piles. In situations such as at the smelter in Tacoma, Washington, where most if not all of the slag is used for other beneficial uses, the reclamation question is not even relevant.

Because of the inert characteristic of the slag expected to be produced from the smelting of manganese nodules, it is anticipated that reclamation efforts will be minimal and probably consist of placing a soil layer over the slag pile as it is built up and revegetating. The exterior slopes of the slag pile would be constructed as flat as practical with the maximum steepness of 3H:1V and preferably a flatter slope on the order of 5H:1V. Typically the slopes are divided by 3- to 5-meter (10- to 15-foot) wide benches at intervals of about 12 m (40 feet) vertically. These slopes with a properly placed soil cover and established vegetative cover would be stable and would produce aesthetically pleasing reclamation of the slag pile.

It is generally assumed that the smelting process would be a four-metal extraction and that the majority of the value metals would be removed from the nodule matrix. In this case recoverable metals would be minimal in the slag. However, a four-metal plant operator may choose not to recover all the manganese in the slag at the time of initial processing. If at a future date it were desirable to reprocess the slag to obtain additional value metals, this procedure could be easily accomplished with the landfill disposal system. However, when the slag is used for beneficial uses of whatever type, the possibility of further recovery from these slags is nonexistent. Therefore, in evaluating the beneficial use of the slag, the potential for future recovery of metals must be balanced against the beneficial use that it is planned for, and a decision made as to whether it is more beneficial to store the slag for future recovery or to use it for road fill, decorative rock, or whatever the market demands.

Slurry Disposal

Seven different disposal techniques were discussed for handling slurried nodule rejects. These range from cross-valley dams to backfilling of surface or deep mines. All of the methods except backfilling of deep mines or deep well injection involve a surface type of facility that would require extensive reclamation prior to abandonment. The deep mine disposal method would not require reclamation in the conventional sense and therefore is not discussed further. Reclamation of slurry mineral wastes primarily means providing a cover over the entire tailings disposal facility in such a way that the cover sheds water but yet is stabilized. Flat slopes (3H:1V or flatter on sides; 3% or flatter on top), riprap, or other materials are used such that the tailings are relatively secured against surficial erosion. Normally this is accomplished by placing a few feet of soil over the dry tailings surface and then revegetating the surface. Critical areas where

water is likely to collect and run off are often ripped to provide a higher degree of protection than the vegetation provides.

The major obstacle to performing this type of operation is transporting the soil over the tailings and grading it, because the slurried tailings typically retain moisture for a long period of time and are relatively unstable with respect to supporting large construction equipment. In general, the slurry waste materials will stabilize more quickly in a dry climate than in a wetter climate. Based on the expected characteristics of the slurry waste, we anticipate that the greatest difficulty with respect to reclamation would be for those wastes obtained from the four-metal hydrometallurgical processes where the wastes are finest and most likely to retain water for longer periods of time.

There is a difference with respect to disposal techniques in the amount of reclamation that is required. That is, the smaller the surface area of the final disposal facility, the less the amount of reclamation that is required. For the two disposal techniques that involve backfilling--excavated pits and surface mines--wastes are generally easier to reclaim and more stable because the final reclaimed surface is relatively small, owing to the greater depth of the tailings material possible. Also, since the reclaimed surface is level or below the adjacent ground surface, erosion is less with this type of situation than for built-up dams, ring dikes, or landfills where water is forced to run over the reclaimed surface.

Liquid disposal in an evaporation pond is a special category where relatively little solid material will accumulate in the disposal facility. In most cases in current application, the evaporation ponds are periodically dried up and the sediment that has collected in the pond is cleaned out and taken to the solid waste disposal facility. At a minimum the reclamation of an evaporation pond requires cleaning up the pond area and removing other material to the solid waste disposal area. Because of significant sea salts in the decant water which would remain after evaporation, covering the evaporation pond area and providing long-term containment may be required.

For all of the disposal methods for hydrometallurgical process wastes, except deep disposal in an underground mine or similar facility, recovery of the waste for extraction of additional value metals would be relatively easy. In most cases the waste would be reslurried and pumped to the processing facility. In the case of the dewatered tailings disposed in a landfill situation, the likely procedure would be to use large earth moving equipment, such as front end loaders and trucks, and haul the dewatered tailings to the reprocessing facility. In the case of disposal in a deep mine, the retrieval of the tailings would be subject to the particular characteristics of the underground opening into which the tailings were placed. The limitations to their recovery would probably be more from an economic view than from a technical view. That is, these tailings could also be reslurried and pumped to the surface, but additional costs would be involved because of having to work in an underground environment where greater pumping heads and more difficult extraction conditions would be encountered.

REPRESENTATIVE SITES FOR ONSHORE NODULE REJECT DISPOSAL

Purpose of Selecting Representative Sites

An environmental assessment can be performed at a number of different levels, with the assessment becoming more detailed and more reliable as the site becomes more specific. Since commercial-scale nodule recovery and processing are not imminent, specific sites for processing and waste disposal for a manganese nodule operation have not been identified by industry. Therefore, the sites that would actually be used for waste disposal cannot be assessed at this time. Areas that could be of potential interest to the marine mining industry for nodule processing and related facilities have been identified in studies prepared for NOAA, which are discussed below.

In preparing the Deep Seabed Mining PEIS, NOAA recognized that most impacts of onshore processing and waste disposal are largely site-specific and cannot be fully assessed at this time (271). Therefore the assessment of the effects of onshore waste disposal in the PEIS is generic and does not consider differences in waste disposal related to different geographic regions or areas or sites within these regions. Potential environmental impacts are listed and characterized in the PEIS as avoidable (typically by siting) or inherent in the waste disposal process, but differing in magnitude for different sites and designs of the waste disposal facility. In both cases the location of the site is necessary to establish the probable effects.

In order to perform a state-of-the-art assessment that contributes information useful to BuMines in further study of onshore nodule waste disposal problems, it was necessary to select representative sites, that is, sites that would likely be considered by industry after they consider relevant site selection factors for onshore facilities. The sites were used to (1) provide a tangible geographic unit for which detailed information, including information from site visits, could be collected and (2) establish a reference point for evaluating other sites in the region that the site represents. To understand why it is necessary to select representative sites as defined above, consider that even for a specific region such as the Pacific Northwest and for a more specific area within the region such as within 50 miles of Puget Sound, there are considerable variations between sites in terms of physiographic, climatic, and geologic characteristics that are important to waste disposal. Selecting a representative site has the advantage that a realistic combination of considerations relevant to waste disposal that occurs in a geographic region can be examined in some detail for assessing potential effects. Trying to conduct an assessment on a "site" such as the Gulf Coast or the Pacific Northwest is prone to too much generalization or averaging of conditions. The resulting assessment does not necessarily reflect conditions at either the best site or the worst site or, in fact, at any site within the region. We have tried to select sites that have more favorable conditions for waste disposal, since industry can be expected to avoid or mitigate potential problems where possible by the judicious selection of a site.

Related Studies Sponsored by NOAA

During 1976, the predecessor of NOAA's Office of Ocean Minerals and Energy began a multiphase program to assess potential onshore coastal zone effects of deep seabed mining. Phase I described and quantified the parameters of marine and onshore nodule transportation, nodule processing, and reject disposal of importance for the performance of subsequent environmental and socioeconomic impact studies. As part of

Phase I, it was necessary to identify nodule processing techniques considered likely for early commercial use and to estimate production quantities. The feasibility of at-sea processing was also considered but was found to be rather unlikely for first generation operations. Phase II identified and described broad geographic areas considered to be representative of areas likely to be considered by industry for onshore facilities. The results indicate how location may influence potential effects. As somewhat of an extension of Phase II, a joint project was undertaken with the State of Hawaii's Department of Planning and Economic Development (DPED) to assess potential effects on a more site-specific basis. Also as a growth of Phase II there was a decision to sponsor studies that identified and described Federal and State laws applicable to onshore nodule processing and related activities.

The principal studies within this program are listed below.

- (1) Description of Manganese Nodule Processing Activities for Environmental Studies. Dames & Moore, 1977, Volumes I-III (80, 95, 96). Volume II is an extensive discussion of transportation and waste disposal systems associated with various manganese nodule processing activities. Gulf Coast and West Coast areas are discussed with regard to sea transportation. Hawaii is not considered. (Benjamin Andrews II was the consultant on sea transportation.) This report was prepared for the NOAA Phase I study on manganese nodule processing and has been relied on heavily in the Phase II studies for specific geographic areas.

- (2) Gulf Coast Manganese Nodule Processing Plant Location Criteria. Texas A.&M. University Sea Grant Program, August 1979 (34).

This study identified physical/economic and regulatory/attitudinal criteria for processing plant locations in the five Gulf Coast states through questionnaires, interviews, and workshops. Ten geographical locales were identified as exhibiting sufficient potential to justify further study. The criteria and relevant features are discussed in this report for each of these 10 areas. The criteria are not specifically defined except for distance to a 40-foot-deep channel and railroad access. The areas that would be selected by the criteria are not mapped.

- (3) Identification of Representative West Coast Areas for Nodule Processing Activities. Oregon State University, 1978 (312).

This Phase II study is the West Coast counterpart of the Texas A.&M. study and follows a somewhat different approach. The physical criteria for processing plant sites are few but well defined and are mapped to indicate representative areas in a general way. Not all criteria are completely mapped because considering them comprehensively on the West Coast would have been very time consuming. General environmental characteristics are described for each of the eight areas identified.

- (4) The Feasibility and Potential Impact of Manganese Nodule Processing in the Puna and Kohala Districts of Hawaii. Raymond W. Jenkins, M. Karl Jugel, Kent M. Keith, and Maurice A. Meylan, November 1981 (176).

This study has been prepared jointly by NOAA and DPED. A "scenario" approach is applied to two sites on the island of Hawaii. One site--Puna--is on the windward (wet) side of the island; the other site--Kohala--is on the leeward (dry) side of the island. Considerable detail is provided in each

scenario about processing techniques, marine terminals, energy options, environmental considerations, and mining industry economics. By focusing on specific areas, this study provides significantly greater insight into the likely workings of a nodule processing operation than the other studies, but at the expense of not being a comprehensive discussion of possible manganese nodule operations on the other islands. Applicability to other islands can be inferred from the report but is not explicit. Extrapolating the results to other islands and defining representative areas for nodule processing activities as was done for the Gulf Coast and the West Coast would require judgments.

- (5) An Analysis of Applicable Law Concerning Seabed Mineral Processing in California, Washington, Oregon, and Alaska. Nossaman, Krueger & Marsh, 1980 (304).
- (6) Analysis of Applicable State and Federal Laws Applicable to Manganese Nodule Processing on the U.S. Gulf Coast. Boston Technologies, Inc., 1981 (33).

These last two studies have been described in the **Chronology of Related Environmental Studies.**

Determination of the Limits of the Five Siting Regions Considered

In order to define the outer limits of a study area for performing an environmental assessment of onshore manganese nodule reject disposal, five siting regions were considered, as specified in the statement of work: Hawaii (wet climate), Hawaii (dry climate), the Pacific Northwest, the Gulf Coast, and California (Northern, Southern, or San Francisco Bay Area). Although the representative areas identified for the Gulf and West Coasts were generally used for choosing representative sites for this study, the sites were chosen based on independent work during this study. The more specific studies for Hawaii directly influenced the choice of representative sites.

The approach used by this study to define the outer limits of the five siting regions is to update, synthesize, and provide a consistent format for applicable sections of the reports described above. The studies relating to areas for processing plants were extended to define areas for waste disposal. This study did not redo these earlier studies or attempt to compensate for shortcomings that may have occurred in them.

In limiting the areas we are considering in this study, it is important to note our assumptions. We have defined five siting regions based on previous studies, our own research in this study, and professional judgment. This does not imply that the deep seabed mining industry would select any of the sites identified nor does it imply that the sites are recommended or ideal sites. Indeed, industry will, and should, consider sites outside of these limits.

The study area is based on reasonable boundary conditions for economically feasible sites. Economic trade-offs could influence a deep seabed miner to exceed one or more of these boundary conditions, for example, to upgrade a port or build a dedicated port for an otherwise excellent site. The marine mining industry would be expected to consider total system economics, which is considerably more complex than precise limits as used in the criteria. The boundary conditions of the study area will vary with the consortium, the type of process, the regulatory climate, and economic conditions.

In completing this task, the following potential trouble spots were noted:

- (1) Ports having 12-m (40-foot) and greater channel and alongside depths are limited in number. The previous studies did not comprehensively map, tabulate, or otherwise indicate all relevant ports and channels in their respective study areas with their authorized project depths, actual controlling depths, and reasons for considering or eliminating specific ports. This information is available (269, 270, 437), but not in a compiled form that indicates the existing and proposed conditions. Largely because of increased demand for coal exporting facilities and oil terminals, the status of U.S. port and channel projects is changing constantly and must frequently be reexamined for current conditions.
- (2) Maps of the representative areas, except for Hawaii, were either unclear or were not produced. In order for Rogers, Golden & Halpern to consider representative areas we have mapped the criteria at 1:500,000-scale for each state as working maps and provided a 1:2,500,000-scale map(s) in the report for each siting region.
- (3) Although a number of different transportation options for nodules and wastes were mentioned in the previous studies, they had not been incorporated in the criteria resulting from those studies.

This section begins by summarizing transportation systems for nodules, processing materials, products, and wastes as well as relevant transportation considerations in each geographic area. Following the description of transportation by component, we discuss the criteria that were developed or can be inferred from each of the previous studies and suggest modifications where appropriate for waste disposal sites. Maps are included for each of the five siting regions considered that indicate representative areas and sites used in the environmental assessment procedures developed in other tasks.

Transportation Requirements

The rate at which manganese nodules are mined, in conjunction with port or channel depths and distance from the mine site, determines the storage requirements for the mining ship(s) and the capacity of and number of vessels in the transport fleet. Nodule throughput also determines the capacity requirements of port handling systems and onshore nodule transportation systems. The quantities of process materials used and waste produced are also dependent on throughput. Therefore, a logical starting point in discussing transportation requirements for manganese nodule processing activities is the assumed rate at which nodules are mined.

The Dames & Moore/EIC 1977 report arrived at the following mining rates based on conditions at the time of the report: for a three-metal processing plant, 3.7 million mtpy (4.1 million tpy) wet and 2.2 million mtpy (2.5 million tpy) dry; for a four-metal processing plant, 1.1 million mtpy (1.25 million tpy) wet and 0.7 million mtpy (.75 million tpy) dry. The three-metal process rate was based on likely capital investment consistent with a satisfactory return on investment. The four-metal process rate was based on the available U.S. market for manganese.

Recent reports (181) indicate that by the time plants are actually built, there may not be a significant difference in throughput for three- and four-metal plants. That is,

four-metal plants would also process about 4 million mtpy of drip-dried nodules--a substantial increase from previous estimates.

In general, both the Texas A.&M. and Oregon State studies used the mining rates as developed by Dames & Moore. The higher four-metal plant throughput has only been used in the Hawaii study.

From the standpoint of determining representative areas for nodule processing activities, it is satisfactory to be aware of the range of the above throughputs. We assume throughputs in the 1-4 million mtpy range. The processing rate for three- and four-metal plants is discussed in **Manganese Nodule Processing Options**.

Transportation Modes

At Sea

Mined nodules will be transferred from a mining ship to a transport ship as either a slurry, whole nodules, or dried and ground nodules. Dried and ground nodules handling would be unlikely except for transport to Gulf Coast ports where longer shipping distances and Panama Canal transit are involved. The approximately 30% reduction of nodule weight by drying would require fewer transport ships. For slurry, whole nodule, and dried nodule handling, respectively, pipelines, enclosed conveyors, and pneumatic loading and unloading equipment would be used to transfer nodules from the mining ship to the transport vessel.

In addition to weight reduction for dried and ground nodules, the primary effects of the type of handling on the overall transportation system are as follows:

- (1) Slower transfer rates from the mining ship to the transport ship may require larger transport vessels or more of the same size vessels. (Slurry pipelines have the fastest transfer rate, pneumatic conveyors the slowest.)
- (2) Different types of transport vessels may be required (for example, dry ore carrier for dried nodules versus slurry carriers).
- (3) The form of transported nodules influences port handling and onshore transportation requirements.

For determining representative onshore areas, the major influence of the transport fleet is in determining suitable ports or dedicated port sites for bringing nodules onshore. Shallower draft vessels can obviously be used to make more port areas accessible, although usually at increased cost of transportation.

Ports

Handling systems at ports will be of three kinds--slurry, dry bulk, or pneumatic (for dried and ground nodules only)--each requiring a different type of marine terminal. Land requirements are about 4-10 hectares (ha) (10-25 acres) for the marine terminal, usually 8-10 ha (20-25 acres) for a slurry or dry bulk terminal, and 4 ha (10 acres) for a lower-throughput dried nodule terminal. At the regional scale used by the previous studies, land availability had not been a criterion used to eliminate any port.

Likely transport fleets (with the exception of tug-barge combinations) include fully loaded vessels in the 40,000-70,000 dwt range; 55,000-dwt vessels are about the maximum-size ships that can transit the Panama Canal because of limits on the length, beam, and draft of the vessel in the freshwater part of the Canal's locks (Panamax vessels). The 70,000-dwt vessels approach the draft limitations of the larger U.S. ports. For the most part, vessels to be used for transporting manganese nodules require 12-m (40-foot) or greater depth in improved channels or existing deep water. The three previous studies considered different port and channel depths which ranged from 10.5-m (35-foot) depths for Hawaii to a 12-m minimum depth in the Gulf of Mexico. Because of the importance of major ports and since some 9-m- (30-foot-) deep ports have channels of greater depth leading to them (which would enhance the possibility of further dredging), a depth of 9 m is the cutoff between ports with potential for improvement or use that are considered by this study, and those that are not considered. Ports with authorized project or controlling depths of 9 m or greater are shown in table A-1. Obviously, using shallower ports will require additional financial and political commitments, but they cannot be ruled out without examining other locational factors that might prompt the marine mining industry to consider these areas. Specially designed shallow draft vessels can increase the deadweight tonnage that can be carried by each transport vessel in shallower ports. In the previous studies by Texas A.&M. and Oregon State and the recent study for Hawaii, channels and ports with available depths of 10.5-12 m have been considered.

Each of the ports listed and mapped in Appendix A might be considered by the nodule mining operator. Although the type of handling system to be used for nodules is not known, previous studies seem to favor slurry handling systems as the most likely for West Coast and Gulf Coast ports, except where the nodules have been dried and ground to reduce marine transportation requirements. Hawaii-based nodule activities would seem to favor dry bulk handling because of the need to handle coal, limestone, and other dry bulk materials in the same port to support the processing operation.

An offshore mooring is discussed as an alternative port in each of the nodule processing studies. However, the use of a single point mooring (SPM) is not resolved completely in the previous reports. The Texas A.&M. report states that "A single-point mooring (offshore) may be a feasible alternative to an onshore port" but does not clarify specific locations where an SPM might be used. In most of the Gulf Coast, the depth of the Panama Canal is the limiting dimension; that is, even if channels were deeper, transport ships would be limited to about 12-m draft. Texas, Mississippi, and Alabama ports and channels with adequate depths are available at reasonable intervals--160 km (100 miles) or less--along the coastline. On the Louisiana and Florida coastlines there are approximately 320 and 480 km (200 and 300 miles) respectively between major ports and channels. However, in these areas 12-m-deep water is usually 30-50 km (20-30 miles) offshore. Based on this analysis, it would appear that offshore ports for manganese nodule transport vessels would not be likely in the Gulf of Mexico.

The Oregon State study for the West Coast considers an offshore mooring feasible for Southern California from San Luis Obispo south because of deep water close to shore and a suitable envelope of winds and significant wave heights. No specific port locations were analyzed. Conflicts with shipping traffic and offshore oil operations were also not considered. Because transport ships periodically require servicing and crew and supply changes in an onshore port, it is not clear that offshore moorings provide any significant advantages in Southern California or, in fact, in any area where existing deepwater ports occur.

Hawaii, for the most part, has very deep water (up to 20-150 m [65-570 feet] near the shoreline) so that construction of new piers and breakwaters (that is, a dedicated port) where required would be an alternative to using existing ports.

For identifying representative areas for manganese nodule activities, the location of suitable ports or locations for dedicated ports or offshore mooring areas is the most important consideration. Types of handling at ports will influence onshore transportation systems but will not influence the choice of a port unless an existing terminal facility for that type of handling is required. This has not been specified in any of the studies reviewed, although obviously an existing dry bulk terminal with adequate unused transfer capacity and support area would be a plus for a specific port area.

Onshore Nodule Transportation

The type of onshore nodule transportation system required depends on the form in which nodules are delivered to port, the handling facilities proposed at the marine terminal, the existing transportation system onshore, and the process to be used to recover value metals from nodules. As with marine terminals the basic transportation forms are slurry (pipeline), dry bulk (unit train/truck/conveyor/barge), and dried and ground nodules (unit train/truck/conveyor/barge). Likely onshore transportation modes have been considered for each siting region in defining representative areas.

For the West Coast, slurry pipelines were selected as the most likely form of nodule transport by the Oregon State report. Assumed reasonable limitations on slurry pipelines were the primary criteria used by Oregon State to define areas around ports. However, alternate scenarios, which were mentioned but not developed fully, provided for rail, barge, or pipeline transport in Washington and Oregon to an area east of the Cascades where evaporation would exceed precipitation; and transport to desert areas in Southern California to avoid conflicts with land use and high land prices along the coast.

For the Gulf Coast, all transport methods were considered by Texas A.&M. The criteria developed for processing plant locations were based on distance from port and the presence of an adequate rail and highway transportation system.

For Hawaii, slurry and dry bulk transportation were considered in the NOAA/DPED study. Dried nodules were not considered because of Hawaii's close proximity to the mine sites. Dry bulk handling seemed to be favored because of the shorter distances from the port and the need to have a dry bulk handling system for process materials. A scenario was analyzed with slurry transportation; however, oil (delivered by pipeline) was considered as the fuel, and waste disposal was at sea via a return pipeline.

Process Materials Transportation

Processing of manganese nodules for a four-metal plant requires substantial amounts of several dry bulk process materials, including limestone, silica, and iron ore, and liquids such as sulfuric acid. Three-metal plants also have large bulk process material needs.

Movement of bulk process materials to the plant site is a major transportation-related determinant for identifying possible processing plant locations and indirectly for waste disposal locations. There are substantial differences in process material transportation systems for the West Coast, the Gulf Coast, and Hawaii.

West Coast sites will probably have bulk process materials delivered to the site directly by rail from inland chemical plants. This was an assumption of the Oregon State study and was reflected in the criterion that processing plant locations would be no more than 24 km (15 miles) from railroads over relatively flat terrain. Alternate transportation schemes were not considered.

The Texas A.&M. study mentioned possible rail and highway transportation systems for the transportation of nodules and wastes. Barge transportation, which is used extensively on the Gulf Coast region for transporting chemicals, was also mentioned with regard to the Gulf Intracoastal Waterway. However, transportation requirements for process materials were not explicitly considered. Rail transportation was included in the physical/economic criteria as follows: "Location of the plant in relation to rail service assumes no new track construction will be required, except for sidings to the plant" and "Rail service from port to site, with good connections for inbound coal shipments, is important." This criterion implicitly considers process material transportation by rail. No criterion was developed for access to water transportation systems.

The Hawaii study uses two explicit scenarios that call for movement of bulk process materials by road or by a combination of conveyor and a dedicated roadway or guideway. Process materials would be delivered to the same port as the nodules. Distances from ports in Hawaii are usually less than 16 km and are in generally undeveloped areas, so this option is possible. Since the process chemicals are not produced on the islands, their delivery is from the mainland and therefore is port-oriented. Ports large enough to receive 1-4 million mtpy of manganese nodules would be adequate to handle process materials as well.

Coal Transportation

Manganese nodule processing plants use substantial amounts of energy either as steam or electricity. Other than nodule transportation, the largest volume of material transported to the processing plant will be coal for energy production. Although purchasing power from utilities is a viable way to use less fuel on site by generating less power, it is likely that coal will still be burned in significant quantity to produce process steam and producer gases and that a coal transportation system will be needed.

Transportation of coal would be via the same routes as for dry bulk process materials, which are discussed above. However, the coal tonnage required is considerably more than any of the other bulk materials and therefore places greater demands on the transportation system.

For Hawaii, wind, geothermal, and ocean thermal energy conversion (OTEC) are discussed as possible alternative energy sources to coal-fired boilers. In the reasonably foreseeable future, until commercial versions of these technologies are available and the economics can be examined, it is likely that the marine mining industry would select a site where sufficient coal could be delivered to produce a dependable supply of steam and electricity at a reasonable cost. A further consideration that reinforces this in Hawaii is the absence of substantial electric-generating capacity by utilities, particularly on islands other than Oahu.

Dry bulk delivery of coal for on-site generation is considered in each of the representative area studies as a primary source of energy. Although coal slurry pipelines are a viable technology for coal transportation, this option was not discussed in the West Coast and Gulf Coast reports and was discussed only briefly in the Hawaii report for transport from the port to the site. Currently active coal slurry pipeline proposals (31,

32) could influence site selection in Washington, Southern California, and parts of Louisiana and Florida should these pipelines be available or under construction when the processing plant site is being chosen.

Products Transportation

The transportation of recovered value metals--nickel, copper, cobalt, and manganese--was not discussed in any detail in the Gulf Coast and West Coast studies. More attention was paid to products in the Hawaii study because the transportation of products is port-oriented rather than oriented inland toward steel mills and other metals industry plants. For a three-metal plant the quantity of products would not be significant (about 3% of the dry nodule weight). However, for a four-metal plant at the higher (4 million mtpy) mining rate a significant weight of products would have to be transported (about 650,000 mtpy 715,000 tpy).

For the current study, since the destination of products was not known, no adjustment to areas based on locations of metal-finishing facilities was made.

Waste Transportation

Waste transportation depends on the physical form of the wastes (which depends on the processing route), the waste disposal technique, and the distance from the processing plant to the disposal site. Dames & Moore considered truck, conveyor, rail, and slurry pipeline (both gravity and pressure flow) for the transportation of waste. Barge transport of wastes was neither evaluated nor eliminated as a possible transportation method in their report. The Texas A.&M. study assumed that barges could be used for transportation of wastes.

Given the similar transportation modes for transport of nodules and processing materials, we considered potential processing plant locations as also possible waste disposal sites for nodule rejects. A further reason for considering areas for processing plants for reject disposal is that there are economic and practical advantages to having the waste disposal area colocated with the processing plant.

Locational Criteria From Other Studies

Locational criteria for potential areas for manganese nodule processing activities were contained in the Oregon State and Texas A.&M. studies. The latter study developed criteria for processing plants and related activities, including waste disposal. No explicit locational criteria were developed for Hawaii because specific sites were considered. Criteria developed in the first two studies are listed below.

West Coast, including Alaska (Oregon State University)

- | | |
|--------------|---|
| Criterion 1. | Location within a 100-km (60-mile) radius from existing 12-m (40-foot) channels or ports without crossing the 900-m (3,000-foot) elevation contour. |
| Criterion 2. | Location within 24 km (15 miles) of existing rail facilities over essentially level ground. |
| Criterion 3. | Ability to supply power, land, and water requirements. |

- Criterion 4. Adequate infrastructure as indicated by a population center of 10,000 people or more.
- Criterion 5. Regular major airline service within a few hours travel time of the plant site.

(Criteria 3-5 were considered as optional.)

Eight possible areas were identified using the Oregon State criteria: Valdez, Alaska (Alaska is not considered in the present study); Puget Sound, Washington; Grays Harbor, Washington; Columbia River, Washington/Oregon; Coos Bay, Oregon; Humboldt Bay, California; San Francisco Bay, California; and Southern California.

Gulf Coast (Texas A.&M. University)

- Criterion 1. A 12-m channel serving the port or off-loading terminal.
- Criterion 2. Plant location within 80 km (50 miles) of a suitable port.
- Criterion 3. 1.6 to 6.3 million gal/day of fresh water supply.
- Criterion 4. Purchased electric power available of 0-94.5 Mw.
- Criterion 5. Location of the plant in relation to rail service with no new construction except for sidings.
- Criterion 6. Access to either railroads or barge transportation for inland transportation systems for coal and bulk process materials.

Ten Gulf Coast areas were selected as justifying further study based on the Texas A.&M. criteria as well as attitudes toward processing plant development: Brownsville, Texas; Corpus Christi, Texas; Port Lavaca, Texas; Freeport, Texas; Port Arthur, Texas; Lake Charles, Louisiana; Baton Rouge, Louisiana; Pascagoula, Mississippi; Mobile, Alabama; and Tampa, Florida.

Comparable criteria that we have identified for Hawaii are as follows:

- Criterion 1. Ocean transportation access for nodules, coal, and bulk process materials, preferably via an existing 10.6 m (35-foot) or greater depth port and channel.
- Criterion 2. Elevation less than 750 m (2,500 feet).
- Criterion 3. Location to capitalize on alternative energy sources (geothermal well fields, winds, and so forth).

Criterion 1 assumes tug-barge transport with 35,000-dwt barges, although planned improvement of harbors to 12 m would be an alternative way to permit sea transport by Panamax (55,000-dwt) vessels.

Criterion 2 was based on our judgment. The sites considered in the scenarios were at elevations less than 750 m (2,500 feet), and 100 m (328 feet) of elevation difference between the port and the plant was considered in the Puna scenario.

Certain modifications to the preceding criteria were included in defining representative areas for manganese nodule reject disposal.

For the reasons discussed earlier under **Transportation Modes**, all ports with a depth of 9 m (30 feet) or greater are considered and mapped in the present study. Areas with water depths naturally greater than 12 m near shore, such as in Puget Sound, are also considered.

For the West Coast, it was not possible within our scope of work to implement the distance to railroad criterion precisely as written. The terrain analysis required would be extremely time consuming. From preliminary analysis of the maps there are not many areas greater than 24 km from railroad within the 100-km envelope of ports and potential dedicated ports, so that only by evaluating terrain would some areas be dropped as representative areas. For waste disposal sites the terrain requirements for railroads may not have to be met anyway, since the processing plant could be located in flat terrain near the railroad while the wastes would be delivered to the disposal site by means other than railroad. For defining the outer limits of the study area we have used a 100-km radius from potential ports and excluded areas at elevations greater than 900 m and areas that could only be reached by a slurry pipeline that must transit through elevations greater than 900 m. Active railroads were mapped within this area and areas greater than 24 km from railroad corridors are included. Based on the proximity to railroads criterion, islands such as the San Juan Islands in Washington and islands in the Santa Barbara Channel in Southern California were not considered for this study. In addition, most of the Olympic Peninsula is greater than 24 km from railroad as well as having elevations greater than 900 m.

For the Gulf Coast the criteria were generally left unchanged; however, we have mapped the ports and channels and the 80-km radius around them and showed relevant rail and water transportation routes within the radii, which had not been done in the Texas A.&M. study. We also included ports such as Panama City, Florida, that were not included by Texas A.&M. It is not clear how rigidly the port depth criterion was applied in that study, since ports with drafts less than 12 m are listed. We included all major ports in the Gulf Coast in defining our study area.

For Hawaii, criteria generally had to be inferred from the scenarios. We considered a specific maximum elevation criteria, which had not been considered for pipelines or conveyors. Because of deep water near shore, the size of the islands, and generally suitable wind and wave conditions, we feel that no area in Hawaii could be ruled out as being too far from a potential marine terminal. Existing inland transportation systems were not considered in Hawaii because transportation flows are outward-oriented (that is, toward ports).

In Hawaii two different siting regions are established based on the difference between annual evaporation and annual precipitation. Although typically the windward side of the island is the wet side and the leeward side is the dry side, it would be difficult to establish a region boundary based on windward versus leeward. It would also be inaccurate since there are exceptions.

Rainfall records for Hawaii are excellent; however, evaporation records are limited and usually are private records of sugar growers specific to the locations of their operations and typically at lower elevations (155). For the Hawaii DPED study (176), Thomas Schroeder produced an analysis of net evaporation for the Big Island. Based on Schroeder's results, we have used the 125 cm/yr (50 in/yr) rainfall contour as the boundary of areas of net water gain (wet versus dry regions). Although Schroeder's work

is strictly applicable only to the island of Hawaii, we have used 125 cm of annual rainfall as the boundary between wet and dry climate regions on all of the islands (figure A-12). We confirmed that this boundary was reasonable based on vegetation maps of the islands. Schroeder also indicated that this distinction was reasonable for Oahu.

The mapping of the outer limits of the five siting regions is shown in Appendix A.

Choice of a Study Area in California

The statement of work for this project specifies that one area of the three in California--Northern, Southern, and San Francisco Bay Area--be selected as a study area for the environmental assessment. These same three units were considered by Oregon State. With the information available so far, it is not possible to establish that one of the three areas would be preferred by the marine mining industry; however, the following points were considered:

- (1) Humboldt Bay/Eureka is the only port area available in Northern California. This is not a major port on a scale comparable to Los Angeles-Long Beach, San Diego, or ports in the San Francisco Bay area, and its depth is less than 12 m.
- (2) Rainfall exceeds evaporation in Northern California, making tailings disposal more difficult.
- (3) Northern California is similar to coastal areas in the Pacific Northwest for a study of this type. Therefore, using Northern California would not assess as many different representative conditions.
- (4) Only a limited area in Northern California is available, considering all the regional criteria.
- (5) Southern California ports and offshore areas are generally closer to the areas of commercial interest.
- (6) Offshore moorings are feasible in Southern California south of San Luis Obispo, but offshore oil activity would have to be considered.
- (7) Conflicts with populated areas are a problem in most of coastal Southern California unless transportation of nodules to sites in the desert is considered.
- (8) Air quality is an overall problem in Southern California and in parts of the San Francisco Bay region.

Based on this information, no clear reason to favor San Francisco Bay or Southern California was found. Either could be chosen depending on which environmental and economic considerations are given higher weight by the mining operator. Rogers, Golden & Halpern selected Southern California to be the study area for California since a more extensive area with a greater number of possibilities would be considered.

Site Selection Considerations

In order for a marine mining consortium to select sites for onshore disposal of manganese nodule rejects and to assess the potential and expected effects of disposal at

a particular site, there are a number of considerations that the consortium would evaluate and that would be reviewed by the appropriate Federal or State regulatory agencies. These considerations should be evaluated in light of an overall decisionmaking process concerning manganese nodule processing, which involves the choice of the port, the processing plant site, and the expected market for products. An implicit consideration for waste disposal sites is that the site be advantageously situated with regard to sites that meet the nodule processor's locational requirements for the other demands of the venture. This has been acknowledged in defining the boundaries of the siting regions and in selecting representative sites for the present study.

Site selection considerations are either regional or site-specific, and can apply to all processes and waste disposal techniques or only to certain options. For a consideration to be regional it must be amenable to analysis from data which can be collected for the entire region being screened for potential sites. For example, U.S. Forest Service and Bureau of Land Management (BLM) lands, non-attainment areas, and military reservations can typically be mapped on a regional basis (165). On the other hand, critical habitats for species with special status often can only be determined from very detailed site-specific studies, although information on likely species, their ranges and specific sightings, may be available on a regional basis. Very often a siting factor will be considered on both a regional and a site-specific basis; for example, slopes exceeding a certain limit in a large region may be identified as unsuitable for a tailings dam, but slopes below that limit will be rated for their storage capacity and stability as more specific alternate sites are selected.

In general the purpose of regional site selection considerations is to identify areas that are preferred for engineering and economic reasons and to be avoided for environmental and sociopolitical reasons. Site-specific considerations are typically used to narrow the choice of alternate sites based on on-site testing and detailed research on the site and its vicinity.

Table 7 lists the site selection considerations for nodule reject disposal identified by this study. Each consideration is shown as regional and/or site-specific and by process/disposal technique options for which it applies. The following sections briefly discuss each consideration.

Geology

The geologic setting of a waste disposal site is important from four aspects: (1) structural integrity of the containment, (2) protection of usable groundwater, (3) engineering and economics of the disposal system, and (4) conflicts with geologic resources. Specific geologic considerations that pertain to these four aspects are discussed below.

Geologic Hazards

Geologic hazards include such phenomena as landslides, collapsing soils, subsidence zones, liquefiable soils, karstic topography, active volcanoes, and faults. These could threaten the stability of an earth containment structure by removal of support or application of unusual stresses to earth embankments, liners, decant systems, and tailings pipelines. At a regional level the types of hazard common in an area are typically known and hazard locations that have historically caused problems have usually been identified. However, geologic hazards that had not previously been discovered are sometimes detected through a site-specific geotechnical investigation. Geologic hazards

are compensated for by avoidance and special construction methods, usually at higher cost.

Seismicity

The seismicity or earthquake susceptibility of an area, which can be indicated by probabilities of earthquakes of certain magnitude, risk of earthquake damage, and the return period of certain ground accelerations and displacements, is an important consideration in the design of dams to contain tailings. Earthquakes can be associated with ground separation at the surface or with deeper fault movements causing ground acceleration but not surface rifts. Earthquake accelerations can be dampened or amplified by overlying soils, and certain soil types are prone to liquefaction under earthquake-induced stresses. The characteristic seismic parameters for a region influence the design and stability analysis of all dams, including those for tailings impoundments, and can result in flatter slopes, lower dams, special construction, and a dewatering system to prevent liquefaction of susceptible soils.

Hydraulic Continuity/Permeability

The permeability of underlying geologic material and its hydraulic relationship to adjacent geologic formations are essential considerations in determining the suitability of a site for waste disposal. For toxic (hazardous) materials, unless in-place soils or geologic materials have permeabilities of 10^{-7} cm/sec or less, artificial or compacted clay liners are required for solid waste disposal sites over usable aquifers under RCRA guidelines. The objective is to create a closed containment system. For nonhazardous materials, control of seepage is a concern from the standpoint of the water level within and below tailings containment structures as it affects the relative stability of embankments and the amount and quality of water lost from the system.

Permeability is generally correlated to rock type and degree of fracturing or to soil texture. The ideal rock type for a waste disposal site is probably a shale formation, which is very low in permeability, has no usable water in the formation, and weathers to a clay that makes good impermeable construction material. At the other end of the scale are permeable rock types such as sandstone, limestone and any highly fractured rock mass. Of soil materials, only very fine clays will have natural permeabilities low enough to meet RCRA guidelines.

Depth to Bedrock

The depth to bedrock typically indicates whether it is reasonable to create an excavated or partially excavated tailings containment based on whether the excavation would require blasting to remove shallow rock. Although certain types of rock can be excavated without blasting because of the degree of fracturing or the orientation of bedding planes, other types of rock would not be easily moved and would discourage or make economically infeasible specially excavated pits entirely below grade.

Shallow, stable bedrock can also indicate ideal foundation conditions for above-grade dam construction.

Foundation Suitability

The ability of in-place geologic material to support dam construction without excessive settlement is important to a reject containment. Unsuitable materials would have to be removed or otherwise stabilized before constructing a dam over them. Soft

TABLE 7. - Site selection considerations for onshore nodule reject disposal

Consideration	Application			
	Regional ¹	Site-specific ²	Slurry disposal	Slag disposal
1. Geology				
Geologic hazards.....	X	X	X	
Seismicity.....	X		X	
Hydraulic continuity/permeability.....	X	X	X	
Depth to bedrock.....	X	X	X	
Foundation suitability.....		X	X	X
Mineral resources.....		X	X	
2. Terrain				
Local relief.....				X
Slope including valley gradient.....	X	X	X	
Accessibility.....	X	X	X	X
Storage volume vs. embankment construction.....	X	X	X	X
Visibility.....		X	X	
Elevation from processing plant (port).....	X	X	X	X
3. Surface water hydrology				
Precipitation minus evaporation.....	X		X	
Drainage area.....	X	X	X	
Runoff.....	X	X	X	
Probable maximum or design flood.....	X	X	X	
Susceptibility to coastal flooding (hurricanes/tsunamis).....		X	X	
Existing surface water quality.....	X	X	X	X
Public water supply reservoirs.....	X	X	X	
4. Groundwater hydrology				
Groundwater usage.....	X	X	X	
Existing groundwater quality.....	X	X	X	
Aquifer recharge areas.....	X	X	X	
Depth to groundwater.....	X	X	X	

5. Environmental/cultural resources					
Species with special status.....	X	X	X	X	X
Critical habitat areas.....	X	X	X	X	X
Wetlands.....	X	X	X	X	X
Historical/archaeological sites.....	X	X	X	X	X
Parks and recreation areas.....	X	X	X	X	X
Wildlife management areas.....	X	X	X	X	X
Unique natural features.....	X	X	X	X	X
Designated scenic areas including wild and scenic rivers.....	X	X	X	X	X
Important agricultural lands.....	X	X	X	X	X
6. Engineering/economics					
Access to railroad/barge.....	X	X	X	X	X
Distance from port/processing plant.....	X	X	X	X	X
Availability of construction/cover materials.....	X	X	X	X	X
Infrastructure.....	X	X	X	X	X
7. Air quality					
Extreme wind conditions.....	X	X	X	X	X
Non-attainment areas for TSP.....	X	X	X	X	X
PSD Class I areas.....	X	X	X	X	X
8. Sociopolitical considerations					
Land requirements/land availability.....	X	X	X	X	X
Land ownership.....	X	X	X	X	X
Adjacent land use.....	X	X	X	X	X
Downstream land use.....	X	X	X	X	X
Consistency with approved State CZM plans.....	X	X	X	X	X
Conformance with State hazardous and solid waste regulations.....	X	X	X	X	X
Mineral rights/water rights.....	X	X	X	X	X
9. Other					
Characteristics of mine, salt cavern/dome.....	X	X	X	X	X

¹Amenable to analysis from data available for an entire siting region.

²Requires data collection or analysis that can only be performed for a limited number of potential sites.

clays, wetland or marsh deposits, and organic deposits are examples of typically unsuitable foundation soils.

Mineral Resources

The presence of an identified economically recoverable mineral deposit below a potential waste disposal site can represent an obstacle to operating the waste disposal system since current or future access to the resource may have to be maintained by the nodule processor. The resource below the site might compete with waste disposal as the preferred use of the land or, subject to coordination of efforts, exploitation of the mineral resource may provide a made-to-order specially excavated pit or deep mine for waste disposal.

Terrain

Differences in slope, elevation, landform, and surface ruggedness are elements of terrain that affect the height and type of containment(s) that would be constructed, the amount of embankment material necessary to contain a given volume of settled tailings or liquids (in an evaporation pond), the accessibility of the site to construction equipment, the pump or conveyor requirements for moving tailings to and within the disposal site, and the visibility of the disposal site from adjacent properties and roadways. Unlike typical terrestrial mining operations, where terrain conditions for waste disposal are dictated by the topography in the vicinity of the mine site, the nodule processor can be more selective in the choice of reject disposal sites. However, the processor must also consider the importance of ports and is typically going to favor coastal areas and consequently the characteristic terrain within 80-100 km (50-60 miles) or less of the port.

The terrain indirectly determines the area required for waste disposal and the rate of rise of the tailings in the impoundment. The latter in turn influences the rate of consolidation, the rate of embankment construction, and the hydraulic gradient that acts on the bottom of the containment.

Certain protected terrain situations shield the containment from wind and consequently reduce wind erosion.

Local Relief

Relief can be indicated by the maximum or by the average difference in elevation measured over specific distances (for example, 1 km x 1 km) or specific landforms such as valleys. For waste disposal, relief measured over the area of the containment is the relevant consideration but, since the area of the containment to hold a given volume varies with the local relief, it is difficult to establish a fixed unit over which to measure it. Based on approximate estimates of the volume of tailings that would be generated for a three-metal plant, the disposal area should be on the order of 100-1,000 ha (250-2,500 acres) for 25 years of operation. On this basis measures of relief over areal units 1-3 km (.6-1.9 miles) square would indicate the height of containment that would be required to enclose these areas. Available relief maps for large regions are typically based on larger units, 10 km (6 miles) square and up (418).

Slope

For construction of an embankment, design slopes are limited by slope stability, equipment access limitations, and susceptibility to water erosion. Slope is also important to establishing vegetative cover during reclamation.

Certain types of liners have maximum slopes above which they cannot be successfully installed. Typically the maximum slope on a constructed embankment is on the order of 3:1 to 5:1; therefore, existing ground slopes greater than 25 to 30% would lead to either an impossible situation for construction of a side hill impoundment or a large amount of dam construction for the volume of storage created. When topography is favorable to the construction of a cross-valley dam, the valley side slopes can exceed 25-30% without making the dam infeasible. However, when the valley gradient is more than about 10%, the height of the dam can rapidly increase to 100-200 m (350-700 feet) and more.

Slope is related to relief, but these measures are considered separately. For a uniform slope with no breaks the relief is the product of slope and distance. However, two areas can have the same slope but different relief when breaks in slope or changes in slope direction occur.

Accessibility

Slopes and landforms that interfere with access by construction equipment for placing fill, raising tailings dams, constructing slurry pipelines and decant systems, and reclamation should clearly be avoided. Presence of existing roads is also a consideration in determining access.

Storage Volume Versus Embankment Construction

The volume of embankment construction can be a significant factor in the suitability of a waste disposal site, since in some terrain the volume of the embankment may approach or exceed the volume of rejects stored. This is particularly important with nodule rejects from hydrometallurgical processes since, as noted previously, the rejects will not have a suitable coarse fraction for embankment construction and the dam raises will have to be constructed entirely of on-site soils or borrow material. The embankment will consume land area additional to that for the rejects proportional to its height. Where off-site borrow is used, the area of impact of the disposal facility will be increased significantly.

Table 8 gives estimates of the volume of fill and disposal area required for a given storage volume and height of embankment in several different idealized types of containment and terrain shown in figure 10. Actual numbers will differ based on the settled density of the rejects and the compaction of the fill.

Visibility

The visibility of the disposal site is a function of the amount of projection of the facility above ground, the degree of topographic enclosure of the site, and the distance to and elevation of the viewer and any intervening elements that screen either the viewer or the facility. Usually visual effects are lessened by distance.

TABLE 8. - Volume of embankment and site area requirements for different containment configurations and terrain¹

Type of containment	³ n	Terrain parameters ²		Containment parameters ²					
		s	v	H,m	L1,m	L2,m	A1, ha/cell	A2,ha	VF, million cu m
Fully enclosed impoundment..	1	0	NAp	10	2650	2650	665	1482	3.6
				20	1992	1992	347	1019	9.7
				40	1642	1642	194	808	28.0
				100	1697	1697	118	839	133.3
	6	0	NAp	10	1140	1140	115	1574	6.4
				20	925	925	63	1152	17.7
				40	886	886	40	1031	54.5
				100	1190	1190	34	1368	303.3
	46	.05	NAp	50	4487	1000	353	1251	27.2
				100	1732	2000	190	938	50.8
				200	1654	4000	151	1484	240.0
				200	3696	1333	181	1240	132.7
		.05	NAp	50	1039	1000	62	1285	38.4
				100	870	2000	44	1669	137.6
				200	1439	4000	78	3972	925.7
				100	2238	666	59	1852	123.0
Sidehill dam.....	200	.15	NAp	100	1749	1333	39	2028	223.8
				200	1749	1333	39	2028	223.8
				200	1749	1333	39	2028	223.8
				200	1749	1333	39	2028	223.8
Cross-valley dam.....	1	.05	.25	160	1283	3208	148	206	24.8
				248	1982	2478	120	246	66.2
				127	1019	2547	93	260	24.9
				197	1575	1968	75	310	66.5
	2	.10	.25	160	1283	3208	148	206	24.8
				248	1982	2478	120	246	66.2
				127	1019	2547	93	260	24.9
				197	1575	1968	75	310	66.5

NAp Not applicable.

¹Based on a total volume of storage (VS) of 65 million cu m for 25 years (approximately 2.7 million cu m/year--the estimated three-metal hydrometallurgical process settled volume from table 6).

²See figure 10.

³Number of cells in the containment.

⁴Two cells downslope by three cells cross-slope.

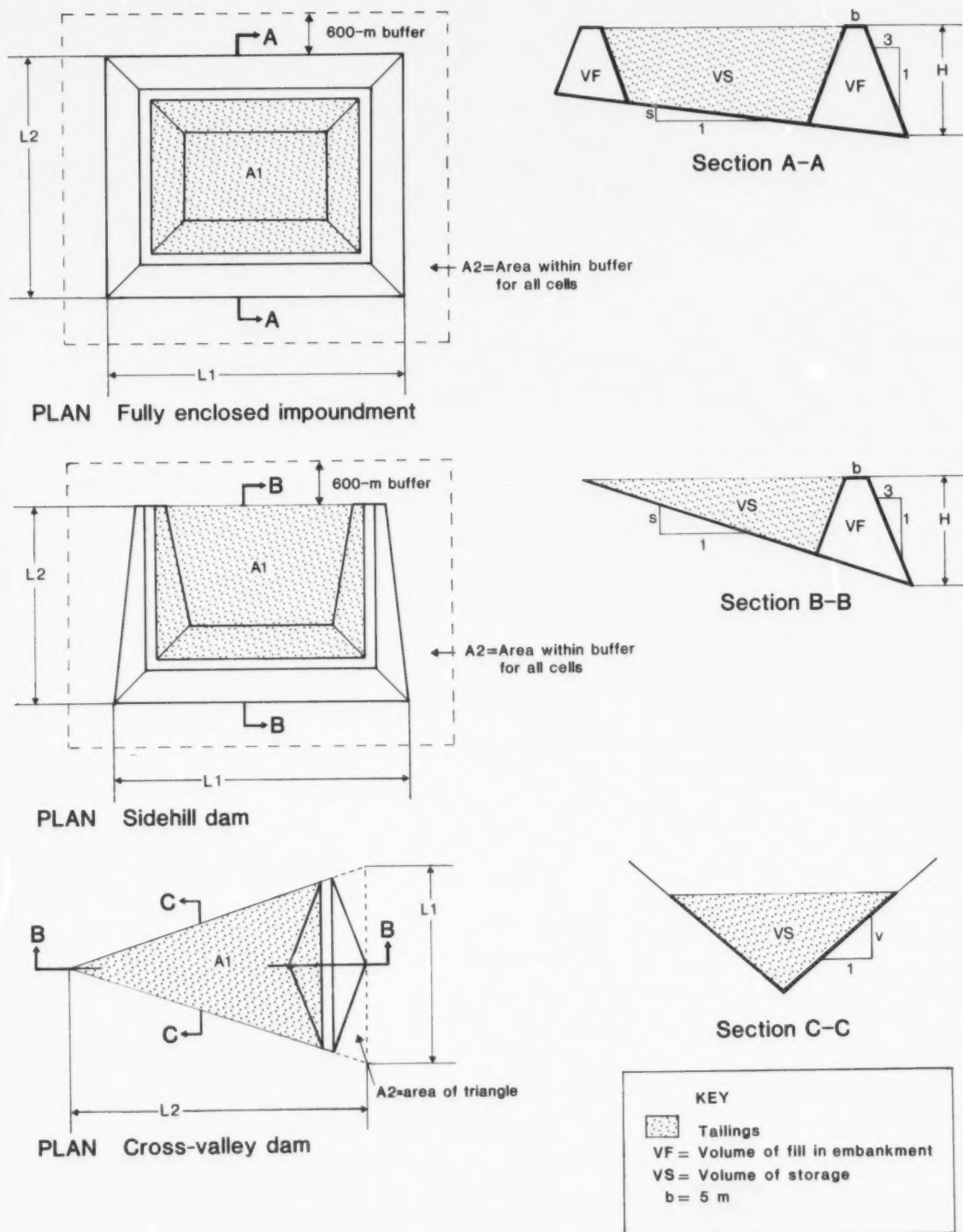


FIGURE 10. - Schematic tailings impoundment plans and cross sections to accompany table 8.

Visibility is typically evaluated on a site-specific basis from selected critical viewpoints by actual observations, although visibility (seen areas) can be calculated from topographic maps for larger regions.

Difference in Elevation From the Processing Plant

Where materials move by slurry pipeline or conveyor, the energy required to transfer the rejects depends on difference in elevation. Since the processing plant location is not yet known, the difference in elevation from the port to the site is the only available indicator of the operating costs associated with higher elevations. Because the nodules must be conveyed from the port to the processing plant and then the rejects must be conveyed from the plant to the waste disposal site, it seems reasonable to consider the port as a starting elevation.

Surface Water Hydrology

The design of a surface impoundment or other above-ground waste disposal facility considers surface water from two standpoints: (1) protection of the quality of surface water resources and (2) protection of the waste disposal facility from damage by surface water. Waste disposal facilities typically are designed to divert surface water inflows above the containment so that as little water as possible flows into, over, or through the wastes. The scale and complexity of diversions depend on the amount of water that must be handled and the rate at which it is delivered. Excess water entering the containment must be treated as would the liquid wastes. Excess water can also impede drying and stabilization of the rejects.

Precipitation Minus Evaporation

In a system where controlling excess water is important, the balance between precipitation and evaporation is a key consideration. Although much of the water that is decanted from tailings ponds can be recycled, in most circumstances evaporation from the tailings pond is a preferred alternative to treatment and discharge or underground injection for excess liquid waste disposal. In a tailings pond the surface area of the containment is subject to direct precipitation and evaporation so that the area of the containment will accumulate additional water in areas where annual precipitation exceeds evaporation.

We have listed precipitation minus lake evaporation as the relevant consideration, although evapotranspiration is a better indicator for wet tailings surfaces. Under carefully managed conditions evaporation can exceed lake evaporation and approach pan evaporation.

Although net evaporation indicates conditions conducive to drying and stabilizing tailings and eliminating excess water, too high a net evaporation rate can lead to conditions that encourage dusting and wind erosion. Also, in such water-deficient areas consumptive uses of water may conflict with State policy.

Drainage Area

The drainage area above a dam, impoundment, or landfill indicates the amount of land surface that can potentially generate runoff and divert it through the waste facility. In rugged terrain (with cross-valley dams or fills), the usual practice is to locate as close as possible to the head of drainageways to minimize the upstream watershed area. In

this terrain the valleys are narrow enough that a dam to store a significant volume of wastes will block the watercourse and intercept all upstream runoff.

In flat terrain different types of stream pattern usually exist and it is likely that sites of about 1-10 sq km (.4-4 sq mi) can be found that do not block major watercourses. The waste disposal facility may have some water diversion from the drainage divide to the waste containment. In very flat terrain the waste disposal facility will only receive the rainfall that falls directly on the surface of the containment.

Runoff

That part of precipitation that runs off the surface of the land (surface runoff) or flows to streams below the surface as quick return flow, delayed flow, and groundwater flow is called runoff. Measurement of runoff is from streamflow gauges. Not all watersheds, not even those with comparable drainage areas, respond in the same fashion, so in order to assess the impact of an upstream drainage area on a reject containment area, it is necessary to have data on the ratio of annual runoff to annual rainfall.

Probable Maximum or Design Flood

In order to design major dams, which a large nodule reject disposal facility might require, all diversions and diversion structures and the freeboard within the containment must be designed considering the risks to life and property of a catastrophic failure. A design flood is usually based on the 100-year recurrence interval storm or greater up to the probable maximum flood consistent with the meteorology of the area. The probable maximum flood is an extremely rare event, so design for this eventuality is the most conservative practice. Based on the upstream drainage area, the design storm rainfall for the appropriate duration and intensity over the entire watershed is used to determine the amount and maximum rate of inflow that should influence the dam design.

Waste containment structures other than cross-valley dams are typically located outside of floodprone areas for 100- to 500-year storm events because of the serious effects of flooding on earthwork embankments and State and Federal policies associated with floodplains.

Susceptibility to Coastal Flooding

Land areas adjacent to the Gulf Coast are subject to flooding from hurricane-generated storm surges and accompanying wind-generated waves. Although embankments for tailings containment will typically be higher than storm surge levels and not subject to overtopping, the possibilities of scour and hurricane overwash undermining embankment support would have to be considered as well as regulations prohibiting waste disposal facilities in floodprone areas. The predicted 100-year storm surge is often used for determining hurricane-susceptible areas and as a regulatory basis. Hurricane winds should also be considered in establishing freeboard.

For the West Coast and particularly for Hawaii, tsunamis, which are earthquake generated, are responsible for the most serious coastal flooding. Except for winds, similar conditions as for hurricanes apply.

Existing Surface Water Quality

On a site-specific basis where surface discharge of treated decant water is proposed, the existing water quality is a major concern. Where surface waters are

currently below EPA standards because of natural conditions or previous pollution, it may be impossible or impractical to achieve overall water quality standards and other types of discharge may have to be used.

Public Water Supply Reservoirs

Where public drinking water is supplied from surface water reservoirs, any discharge or potential release to streams or groundwater flowing into the reservoir is of particular concern because of the residence time of liquid effluents discharged into the reservoir and the importance of the water supply to the persons it serves.

Groundwater Hydrology

The protection of usable groundwater is a consideration for all of the waste disposal techniques identified. The principal considerations other than the ability of the geology of the site to protect groundwater, which has been discussed in the Geology section, and the characteristics of the rejects are the presence of an aquifer and its suitability as a public water supply.

Groundwater Use

Groundwater areas already in use as public and private water supplies represent a situation where the presence of a usable groundwater resource that must be protected has clearly been established. Federal and State regulations provide protection for existing wells and special protection for sole source aquifers.

Aquifer Recharge Areas

Aquifer recharge areas represent points of entry and replenishment for groundwater reservoirs. For confined aquifers the recharge areas represent the only source of water entry and, in a well-confined system, the primary point of potential contamination by toxic elements or sea salts from rejects. Where possible these areas should be avoided.

For extensive unconfined aquifers, recharge areas can be so widespread that reliance on other means of protecting groundwater may be necessary.

Existing Groundwater Quality

The primary consideration in permitting an activity that could potentially contaminate an aquifer is that the aquifer is not usable as a water supply because of its water quality. High groundwater salinity (total dissolved solids) is a common reason for permitting waste disposal over an otherwise suitable formation.

Depth to Groundwater

Because of the possibly favorable transformations of wastes within the soil profile and the greater chance of polluting the groundwater where there is groundwater near the surface, areas with a deeper water table are preferred as waste disposal sites.

Groundwater at shallow depth can also interfere with the construction of the waste disposal facility and the operation of liners, leachate collection systems, and underdrains

that lower the water level in embankments. Shallow groundwater is normally a fatal flaw for specially excavated pits and backfilling surface mines.

Environmental/Cultural Resources

Environmental and cultural resources are found in land areas that are significant because of their scenic and recreation value, their function in the environment as habitat and for maintenance of environmental quality, their link to our heritage, or their current use in essential purposes. Environmental/cultural resource considerations typically affect siting a large waste disposal facility as prohibitions or restrictions on siting. Where these resources can be identified, they are avoidable primarily by siting the facility elsewhere. At a minimum, these factors lead to more detailed studies, more expensive impact mitigation measures, and possibly modifications and delays to the project.

Species with Special Status

A large project such as a manganese nodule waste disposal site would be expected to come under review by government agencies administering programs to protect species with special status, including endangered and threatened species, marine mammals, and migratory birds.

Endangered and Threatened Species

Endangered and threatened species are protected under the Endangered Species Act (ESA) of 1973, as amended, which created a national program that involves Federal and State government agencies, conservation organizations, individual citizens, business and industry, and foreign governments in a cooperative effort to conserve endangered species worldwide. At the heart of the program is an official list of species designated as either "endangered" (in danger of extinction throughout all or a significant portion of its range) or "threatened" (likely to become endangered within the foreseeable future). Additional species are under review or are proposed for inclusion on the official Federal list.

FWS has the primary responsibility for carrying out ESA, and a number of states have cooperative agreements with FWS which make them eligible for Federal financial assistance in the form of matching funds for developing and implementing State endangered species programs. The FWS Office of Endangered Species, the State agencies administering State endangered species programs, and local experts should be contacted to determine if any records of endangered or threatened species exist for the site under consideration or if the site contains potential habitat for these species. Recommendations should be sought as to whether activities on the site might have adverse effects on endangered or threatened species off-site.

Marine Mammals

The Marine Mammal Protection Act (MMPA) of 1972 protects marine mammals that may be in danger of extinction or depletion. Regulatory responsibility for marine mammal protection, governing the taking or importation of marine mammals or marine mammal products, is divided between FWS and the National Marine Fisheries Service (NMFS).

The effects of manganese nodule waste disposal on marine mammals should be assessed at the site-specific level. Data on the presence of marine mammals and information on the possible effects of a waste disposal operation should be obtained from FWS and NMFS, and appropriate State wildlife agencies should be consulted.

Onshore waste disposal facilities are only expected to have an impact on marine mammals when they are located near the coast where conflicts with such things as seal haul-out areas are possible. Species such as the manatee can also be affected, since they move into bays and rivers and areas closer to possible waste disposal sites. Indirect effects on marine mammals through changes in water quality would be considered but are not specifically addressed under MMPA.

Migratory Birds

Migratory birds are protected under the Migratory Bird Treaty Act (MBTA). Open water such as is found in a tailings pond may attract birds, particularly waterfowl. Toxic substances ingested by birds as a result of preening and feeding activity could cause illness or death and constitute a "taking" under MBTA. There is also some concern among wildlife management officials that consumption of contaminated game birds might result in adverse human health effects. While numerous types of "hazing devices" have been employed to scare birds away from areas where they are not wanted, the long-term effectiveness of such devices is questionable due to a tendency for the birds to become accustomed to the presence of the device.

Wetlands

Wetlands are lands that are transitional between terrestrial and aquatic systems and in which saturation with water is the dominant factor determining soil development and the plant and animal communities occupying these lands. Wetlands include diverse types of areas--bogs, swamps, and salt, brackish, and freshwater marshes. Wetlands are breeding, rearing, and feeding areas for fish and other wildlife. They may perform valuable functions in flood protection and pollution control. Federally owned wetlands are protected from destruction or modification by Executive Order 11990. In addition, no dredging or filling activity in wetlands can be undertaken without a permit from the U.S. Army Corps of Engineers (COE) under the Clean Water Act (CWA).

To avoid contaminating wetland ecosystems as well as for engineering reasons, a manganese nodule waste disposal site should not be located in a wetland. A low water table is desirable for maximizing drainage and drying of the wastes, and for stability of dike construction.

Large wetland areas can be located at the regional level by means of information available from various Federal and State agencies. On the site-specific level, wetlands should be located and eliminated from consideration.

Historic/Archaeological Sites

The effects of manganese nodule waste disposal on places appearing on the national register of places of historic, cultural, and archaeological significance must be considered by Federal licensing agencies under the National Historic Preservation Act (NHPA) of 1966. In addition, the Preservation of Historical and Archaeological Data Act (PHADA) of 1974 mandates the preservation of "historical and archaeological data...which might otherwise be irreparably lost or destroyed as a result of...alteration of any Federally licensed activity or program." Because survey and recovery of such

data could result in significant project delays, known areas of historical and archaeological interest should be avoided when possible. Information on registered places and historically and archaeologically valuable areas should be obtained from the National Park Service (NPS), appropriate State agencies, and local experts.

Parks and Recreation Areas

Federal and State parks and recreation areas are environmental and cultural resources that should be avoided in siting a waste disposal facility. Location of a waste disposal facility in close proximity to such an area could be perceived as an intrusion on the recreational experience and could create an adverse public reaction due to anticipation of noise, visual intrusion, and dust problems.

National parks, national monuments, national seashores, and other Federal and State recreation areas should be identified at the regional level and avoided.

Wildlife Management Areas

Federal, State, and privately operated wildlife management areas or sanctuaries may contain valuable wildlife habitat. These areas should be located at a regional level and avoided when selecting a site for disposal of wastes. A standard minimum distance to maintain around these areas cannot readily be specified because of differences in terrain, habitat type, and the presence of visual and other barriers. One habitat-related consideration, discussed under **Migratory Birds**, is the attraction of wildlife, particularly waterfowl, to open water. Tailings ponds, if they contain hazardous materials, may present a hazard to such wildlife. While it is not possible to specify buffer area widths, placement of a tailings pond immediately adjacent to areas of concentration of waterfowl clearly could pose serious management problems.

An inventory at the regional level should include, at a minimum, FWS wildlife refuges, marine sanctuaries, State wildlife management areas, and National Audubon Society sanctuaries.

Unique Natural Features

Unique natural features are elements of the landscape that are natural in origin and that are particularly representative examples of natural phenomena. In addition to being local landmarks or recreation spots, these features are often of scientific and educational value. Examples of unique natural features are barrier beaches, coral reefs, volcanoes, and escarpments. Some of these areas may already be protected if they are contained within parks or given some other means of protection. Information regarding these features should be sought on a site-specific level. State geological survey offices and other resource agencies often have such features documented.

Designated Scenic Areas, Including Wild and Scenic Rivers

Areas of exceptional scenic or aesthetic value should be considered and their qualities preserved in the process of selecting a waste disposal site. The National Wild and Scenic Rivers System (NWSRS) designates rivers that have scenic, recreational, and other values. NWSRS designations include wild, scenic, and recreational rivers or river segments. States may have wild and scenic river programs in conjunction with the Federal programs. Other scenic areas may also be designated by State or local authorities.

NPS should be consulted for lists of the rivers included in NWSRS, and appropriate State agencies should also be contacted in order to compile an inventory at the regional level.

Important Farmlands

Important farmlands include U.S. Soil Conservation Service (SCS) designations of prime farmland, unique farmland, and farmland of statewide importance. These lands are customarily considered in major land use decisions as potential restrictions to siting certain facilities. In predominantly agricultural areas, important farmlands may be (and often are) so extensive that a facility that requires a large area of flat land would automatically have to compete with agriculture. A tailings impoundment or landfill will also require topsoil in significant quantities to permit reclamation.

While it might not be practical to completely avoid agricultural lands in selecting a waste disposal site, preference can be given to marginal or less productive farms and those situated at the fringe of principal agricultural districts.

Engineering/Economics

Although many of the site selection considerations have engineering and/or economic aspects, the four discussed below are important specifically because of capital and operating costs associated with them and the engineering solutions used to provide the most favorable economics for the project.

Access to Railroad/Barge

Rail or barge channel access is primarily a consideration for smelter slags, which can be marketed for various beneficial uses possibly at a distance from the plant (and temporary waste disposal) site. In order for such off-site uses to be economically practical, there must be a transportation system capable of moving the slag to the user(s) at rates competitive with on-site disposal. This typically mandates an in-place bulk transport system near the processing plant that requires little or no new construction for railroads or dredging and construction of off-site conveyors for barge transportation. In this situation waste disposal will be considered integrally with plant siting, since the process plant also requires a bulk transport system.

Considering long-distance rail or barge transport for hydrometallurgical process wastes would permit different assumptions regarding the limits of the study area.

Distance from the Processing Plant

The costs for constructing and operating a transportation system (such as a slurry pipeline) to move wastes from the processing site to the waste disposal site are a function of distance. Since there is a similar transportation system moving a comparable weight of nodules from the port to the processing plant, it is reasonable to consider a pipeline from the port to the waste disposal site with the processing plant somewhere along its length for selecting a site. Obviously sites closer to the port are preferred. However, neither the processing plant nor the waste disposal site must necessarily be at the port.

Availability of Construction/Cover Materials

It is not expected that the rejects from hydrometallurgical processes will have the necessary strength to be used for containment dams; likewise, the rejects are expected to require cover materials to stabilize against erosion, minimize seepage and leachate generation, and promote the growth of vegetation. Further possible requirements are clay for liner material and gravel for filters and drains. If suitable materials are not available on site for these uses, a penalty is incurred for purchasing these materials, transporting them to the site, and managing the borrow site. Although a typical site will not have all of the necessary soil materials, preliminary soils investigations can avoid a situation where all of these soils have to be imported.

Infrastructure

Although the waste disposal site does not require services to the same extent as the processing plant, there are nevertheless needs for access roads, equipment maintenance, and housing for personnel who would work at the site. In roadless and remote areas these services would have to be provided at additional cost and inconvenience.

Air Quality

Waste disposal considerations for nodule rejects regarding air quality are those that have to do with particulates released into the atmosphere as fugitive dusts from tailings and embankment surfaces and during construction. The releases are greatest for fine-grained materials in very dry and windy climates and exposed areas.

Extreme Wind Conditions

Areas that are subject to high average wind stresses or where winds are concentrated by topography have sites that require special attention to dust control to avoid exceeding air quality standards.

Non-attainment Areas

Primary or secondary non-attainment areas for total suspended particulates (TSP) are areas where national ambient air quality standards (NAAQS) for this class of pollutant are exceeded under existing conditions. Consequently, any new source would further exceed the NAAQS. New sources impacting on a non-attainment area are permitted only when they can achieve a reduction of existing emissions (emission offset) equal to the predicted effect of the new facility. This may be difficult or expensive for TSP, where the NAAQS may be exceeded by large areas of agricultural land use rather than by one or two major point sources.

Prevention of Significant Deterioration Class I Areas

Prevention of Significant Deterioration (PSD) Class I Areas are primarily national parks and wildlife and wilderness areas where any significant deterioration of air quality is unacceptable because of the value of the environmental resource. Tailings disposal sites near Class I areas may find it impossible to operate without causing some particulate releases which exceed the extremely strict air quality standards. This restriction would extend to designated "integral vistas" where visible dust emissions would also be regulated for areas in view of the Class I area.

Sociopolitical Considerations

The proximity of residential areas, other developed areas, or actively farmed areas can be an exclusionary consideration for a waste disposal facility site. Current tailings disposal practice favors remote locations consistent with the remote locations of the mine sites. Nodule reject disposal sites are different in this sense--because of port requirements the rejects will originate on land from a coastal (and typically developed) location. The nodule processor siting the processing plant and the waste disposal facility will balance the economy of closeness to the port with the delays and objections encountered with land use conflicts.

Other sociopolitical considerations besides land use include consistency with State plans and regulations and the possible obstacles of legal problems with rights to mineral or water use.

Land Requirements/Land Availability

For siting a major facility, a typical starting point is to determine the land area required by the facility under various options. The next step is to define areas that will be considered as unavailable and excluded (for the region) from further consideration as facility sites. For a tailings disposal facility, developed areas are typically excluded, as are small, undeveloped areas completely surrounded by development. Although land requirements can be modified by the design assumptions (for example, a greater depth of tailings), the scale of the facility is such that it cannot be fit in among predominantly developed areas.

Land availability also connotes little purchase difficulty and a favorable purchase price, which are usually discovered through real estate analyses only after more specific locations have been identified.

Land Ownership

The number and the type of owners (speculator versus resident) are considerations in assembling any large parcel of land. Although development patterns often reflect ownership patterns, there is no way to identify the ownership accurately for undeveloped areas without analyzing tax or property records. Because of the effort involved in assembling this type of information, ownership is typically considered on a site-specific basis except for major Federal and State landholdings and major property holdings such as large farms or ranches, lumber company tracts, and so forth.

Adjacent Land Use

Without major modifications to the disposal plan, a manganese nodule reject facility will be incompatible with all but heavy industrial and extractive uses on adjacent properties. Some objections can be mitigated by providing additional buffers (that is, by acquiring a larger site); however, siting is the principal mitigation technique for avoiding land use conflicts. Local plans are often considered as indicative of future land use when the facility is projected to operate over a 20-year or greater life.

Downstream (Downhill) Land Use

Developed areas downstream (or downhill) from a tailings containment site, and particularly those that are heavily populated, represent potential objections to the construction of the facility. Issues that may be involved are safety in the event of a dam

break and possible changes in surface water quality. The first issue is most significant for cross-valley or sidehill dams where development has been located within the floodplain of the stream or areas prone to hazards from mass soil movements. The second issue is most significant when the stream plays a major role in water supply or irrigation that can be impaired by operation of the facility.

Consistency With Approved Coastal Zone Management Plans

Federal actions, including those involving manganese nodules, must be consistent with approved coastal zone management (CZM) plans. State CZM plans deal with uses that are permitted or favored within the coastal zone. Although there are significant differences from state to state in policies and priorities and coastal zone boundaries, a common provision of many CZM plans is to restrict development at coastal sites to facilities that are functionally dependent on a coastal location. An onshore waste disposal facility cannot reasonably be said to require a coastal location, so these facilities will typically be located away from the shoreline and outside of the coastal zone, where the zone is defined as a limited distance from the shoreline. Where the coastal zone is defined as the coastal counties or some other broad definition, it would not be realistic to locate these facilities outside of the coastal zone.

Specific provisions of CZM plans can also apply to waste disposal, mining, and activities that are in the national interest. These would have to be evaluated against a nodule venture on a state-by-state basis.

Conformance With State Hazardous and Solid Waste Regulations

State solid or hazardous waste regulations can in some instances introduce requirements more restrictive than or different from Federal RCRA regulations, which must be considered in siting. Examples would be provisions that deal with distance from the processing plant to the waste disposal site, waste classification, and requirements for leachate collection. These regulations and their effect on siting are discussed in more detail in **Regulatory Regimes**.

Mineral Rights/Water Rights

In water-short areas, a facility may have to obtain rights to use water consistent with agreements to maintain a certain flow to downstream users. In areas with high evaporation rates, the tailings pond facility may have to be carefully managed to limit evaporation and to minimize water use for dust control.

Mineral rights below a facility can limit surface operations to maintain access and can also limit the use of underground mines, where the mine has remaining value minerals that may eventually be economically recoverable. Purchase of mineral rights may increase the price of the site and possibly delay acquisition.

Other Considerations

Site selection factors that do not fall into any of the principal categories above have been grouped as other considerations. Although specifics relating to any individual site may introduce additional factors, we have not attempted to identify all of these miscellaneous considerations. We have identified one miscellaneous consideration, which applies only to disposal in existing surface or underground mines or geologic depositories.

In order to utilize an existing mine pit or cavern for waste disposal, it is necessary to determine that the volume, shape, and configuration of the existing mine or cavern are amenable to waste disposal. Such things as the area of openings at the surface and the depth below grade for the mine or cavern are typically investigated in a site-specific study. Large below-ground storage volumes are required, and many sites can be ruled out for this type of disposal based only on the size of a mining operation or a quick analysis of the rough dimensions of a salt cavern or an excavated pit.

Choice of Five Representative Sites

The representative manganese nodule reject disposal sites that have been selected by Rogers, Golden & Halpern for the environmental assessments are presented in table 9. Sites 10 km square were selected at each of these locations to provide a discrete area with specific characteristics, some variability regarding the above site selection considerations, and many possible actual sites. In order to select representative sites, it was necessary to develop geographic data for each siting region that reflected relevant differences between parts of the region. Our characterization of the siting regions was limited to regional site selection considerations identified in table 7 for which information was readily available. Appendix B presents some of this. The representative sites were chosen, based on the consultant's judgment, to perform a realistic environmental assessment. We do not mean to imply that the marine mining industry has considered or will consider these sites.

TABLE 9. - Representative manganese nodule reject disposal sites

Siting region	Representative site	County	Port
Pacific Northwest.....	Near Cherry Point, Washington	Whatcom	Dedicated port
Southern California...	Near Casmalia	Santa Barbara	Dedicated port
Gulf Coast.....	West of Corpus Christi, Texas	Nueces	Corpus Christi
Hawaii wet climate....	Near Hilo airport	Hawaii	Hilo
Hawaii dry climate....	Near Kawaihae harbor	Hawaii	Kawaihae

The general rationale for selecting these sites is governed by the following objectives:

- (1) The sites should be consistent with previous and ongoing related studies regarding representative areas that were or are being supported by NOAA. Specifically all sites are within the regions identified in appendix A.

- (2) The sites should not have conspicuous fatal flaws that would make them completely unrealistic as waste disposal sites.
- (3) The sites should be reasonably representative of conditions likely to be found in selecting a waste disposal site in the siting region.
- (4) The choice of sites should consider regional site selection considerations (for example, general terrain characteristics) that are clearly significant in the siting region.

The following subsections discuss the five sites. **Important Site Conditions**, which is a subsection of **Preliminary Assessment of Environmental Considerations Related to Onshore Nodule Reject Disposal**, presents a map of each site.

Pacific Northwest Site

The representative site chosen for the Pacific Northwest region is near Cherry Point on the Strait of Georgia in Puget Sound and is located approximately 19 km (12 miles) northwest of Bellingham, Washington. In determining a site to be used in the environmental assessment of onshore nodule reject disposal, it is important to consider the port or water orientation of the site since nodules will be delivered from the port in the same way that terrestrial minerals originate at the mine.

Puget Sound is a sheltered waterway with naturally occurring deep water often quite close to shore. Because of this, examining only existing ports would be misleading for, in fact, many of the Puget Sound ports were originally developed to serve the wood products industry and consequently have maximum drafts of about 9 m (30 feet), while 18 m (60 feet) and greater depths are available within reach of a pier or a short dredged channel. Considering the distance from the nodule deposits of maximum commercial interest, it would be advantageous to have a port with drafts of 18 m and greater available to accommodate larger transport vessels and possibly require a smaller transport fleet. The Cherry Point area is well situated in this regard and in fact has been considered as an alternate transshipment port to Port Angeles, Washington, for the proposed Northern Tier Pipeline (399).

There are currently industrial users (Mobil Oil Corp. and Atlantic Richfield Co. ARCO refineries and INTALCO Aluminum Products) that provide their own piers and handling facilities within the site chosen, although both pier space and land would still be available.

A further reason for considering this site is terrain. The volume of rejects generated by either a three-metal or four-metal plant is substantial, and in rough terrain it would be difficult to provide adequate containment or fill areas while maintaining stable slopes. For example, if natural slopes exceed 25% it would be impossible to create large containments while maintaining a 3:1 to 5:1 slope with periodic benches in the embankment. Even using the valleys in the Cascades or Pacific Ranges would be difficult because of either steep valley slopes or large upstream drainage areas. These areas are also largely protected Federal lands. On the basis of terrain it would be likely that better sites would be found in the Puget Trough region, in which this site is found, or in the Willamette Trough.

The evaporative water balance is a further consideration in water control for containment areas. Although the Pacific Northwest west of the Cascades generally has

an excess of precipitation over evaporation (with the exception of a small area near Port Angeles and the San Juan Islands) there is considerable variation in the balance and hence in the amount of excess water to be treated or disposed of. The site has a mean annual lake evaporation between 50 and 56 cm (20 and 22 inches) and a mean annual precipitation of approximately 75 cm (30 inches). Pacific coastal areas and areas in the Cascades have considerably higher precipitation.

The surface geologic formations of the site (as well as much of the Puget Trough) are predominately till and glacial drift. The materials have variable textures and would be evaluated on a more site-specific basis for their properties regarding waste disposal and embankment construction.

The land use of the site other than the industrial sites mentioned is predominately agricultural, including many dairy farms and pastures. Moving east toward Ferndale, residential development increases, and there is also residential development at Neptune Beach. South of the site is the Lummi Indian Reservation.

Southern California Site

The site selected for southern California is 100 sq km (36 sq mi) around Casmalia in Santa Barbara County. Essentially, the site was selected by a process of elimination.

Initially, the ports of San Diego, Los Angeles-Long Beach, Port Hueneme, and Port San Luis were reviewed for suitability to accept manganese nodule transport ships. The ports of San Diego and Los Angeles-Long Beach might be suitable for this purpose. Port Hueneme has no available land around its harbor that could be used to unload manganese nodules; it is filled to capacity, although port officials are currently trying to negotiate for more land to expand the port's facilities. The harbor at San Luis would require extensive improvements before manganese nodule transport ships could be accepted. The greatest depth in the harbor is 10.6 m (35 feet), which is at the end of the harbor's single pier. In addition, it appears doubtful that suitable land around the harbor could be found for storage purposes.

After reviewing the harbors, a survey of the land in the Southern California study area was undertaken. There is virtually no suitable, undeveloped land with an elevation less than 750 m (2,500 feet) within a 100-km (60-mile) radius of either the San Diego port or the ports of Los Angeles-Long Beach. The counties of Ventura, Santa Barbara, and San Luis Obispo contain undeveloped lands of adequate size for a waste disposal facility within 100 km of the coast; but most of these areas do not meet geologic and hydrologic considerations. The most suitable land would probably be in the western portion of the San Joaquin Valley, possibly around McKittrick. Considerations for geologic structures, hydrologic features, precipitation and evaporation rates, and compatible surrounding land uses would all be satisfied. However, the costs of transporting manganese nodules or the processing wastes at least 100 km over two mountain ranges may be prohibitive. Kern County officials have indicated that any waste disposal site in their county would probably be rejected unless the processing plant were also located in the county.

One other factor, which is unique to this area, was considered. California's classification of hazardous wastes is stricter than the Federal standards. Although at this time it is not possible to establish whether manganese nodules would be classified as hazardous wastes, it appears prudent to at least recognize the State's criteria for siting a Class I or Class II-I hazardous waste disposal facility. These criteria are similar to the considerations used in this report. In addition, California's Department of Health

Services (DHS) is sponsoring a hazardous waste siting study for Los Angeles, Orange, San Diego, Ventura, Imperial, Riverside, and San Bernardino Counties. Although this study had just been initiated, two of its principal investigators who were contacted stated unofficially that it appears doubtful that any land within the above counties and within 100 km of the coast would satisfy the State's hazardous waste disposal siting criteria.

There is an approved Class I hazardous waste disposal site within the site area about 2 miles northwest of the town of Casmalia. The Casmalia disposal site is terraced and its elevation ranges from 120-300 m (400-1,000 ft). The underlying bedrock is predominately claystone and diatomaceous shale, and it is texturally homogeneous. Wells in the Sisquoc formation beneath the site generally have low yields and large drawdown curves. Two U.S. Geological Survey wells, which are several miles to the south and west of the site, yield nonpotable water.

The northern portion of the site, where Casmalia is located, is more suitable for mineral waste disposal than the southern portion. Geologically, the northern portion contains upper Miocene marine sedimentary rocks, in which the low-permeability Sisquoc formation is found. The southern portion of the site contains recent sands and the Orcutt formation, which is also sandy. A pre-Quaternary fault (older than 2 million years) runs through the western portion of the site. The area receives an average annual precipitation of between 25 and 50 cm (10 and 20 inches). Current land use in the northern part of the site is industrial, including active diatomite quarries and producing oil fields. The population density is low and many relatively large tracts of land contain no residential housing. Finally, consideration was given to identifying a suitable site close to the coast where a new port could be constructed to transport manganese nodules onshore. The western boundary of the site is 2 miles from the coast and the northwestern corner is 6 miles from Point Sal. Point Sal might be a suitable area from which a "T" pier could be constructed to serve a dedicated port.

Gulf Coast Site

In choosing representative sites for the Gulf of Mexico region it was not possible to choose one site that was reasonably representative of the entire region. The region encompasses five states and there are substantial differences from east to west in climate, geology, land use, and regulations. We feel that, although it would be difficult to extrapolate certain parts of the assessment to other possible sites such as those around the Port of Tampa, the Corpus Christi site is representative of the more likely areas to be considered by industry, particularly because of favorable climatic (water balance) and geologic (soil suitability) conditions.

The Corpus Christi site is a 10 km (6-mile) square located along Highway 44 between the Corpus Christi International Airport and Robstown, southwest of the Corpus Christi Inner Harbor. Most of the site is located in Nueces County, but the northeast corner is in San Patricio County. Oso Creek originates in and flows across the site in a southeasterly direction, and West Oso Creek originates in the southwestern part of the site. Most of the area is in cropland, with small areas of improved and unimproved pasture, commercial, institutional, residential, and extractive land uses.

An essential element of drying tailings without requiring high energy inputs is that evaporation exceed precipitation in the annual water balance. In Corpus Christi the annual water balance indicates a net water deficit--a desirable condition for drying. Areas east of Port Arthur, Texas, generally show a net annual water surplus and thus are not conducive to naturally drying.

The terrain is essentially flat, a distinct advantage in siting a large manganese nodule reject disposal site, but a requirement not difficult to meet almost anywhere on the Gulf Coast. The soils and substrates in the area, however, are particularly well suited to waste disposal. Much of the area is underlain by impermeable clays and muds, including the following geologic units: interdistributary muds, barrier-strandplain swales, abandoned channel-fill muds, overbank fluvial muds, and mud-filled coastal lakes and tidal creeks. These materials exhibit characteristics that make them suitable for waste disposal, particularly as regards leachate control. This suitability is important because the hydrometallurgical leach processes will probably produce tailings that are more permeable than 10^{-7} cm/sec and therefore are too coarse to limit seepage to the values specified in the hazardous waste disposal regulations.

The hydrometallurgical processes also are expected to result in a particle size that is too fine (100% less than 200 mesh) for use in embankment construction. Therefore, it is important that materials suitable for embankment construction be available nearby. Availability of suitable materials should not present a problem locally because of the presence of a number of geologic units containing sands.

Wetlands take up a relatively small portion of the area around Corpus Christi. The water table in the Corpus Christi area is generally low enough over large areas so as not to cause problems with leachate migrating directly into the groundwater system. In contrast, high water tables and marshy conditions predominate in some areas of the Gulf Coast region, such as around New Orleans and the Tampa Bay area.

The Texas coast is highly susceptible to coastal flooding from hurricanes and tropical storms, with the barrier islands being particularly vulnerable. In the inland Corpus Christi area, hurricane-related flooding has been recorded in the areas adjacent to streams, but there are large remaining areas of land that are not subject to flooding. However, high winds from hurricanes could generate wave action within the containment area. The design would have to include higher freeboard to allow for wave action if the disposal site contains open water.

An additional concern is the presence of active or potentially active faults, which must either be avoided or considered in the facility design.

While the predominate land uses around the port are farming and extractive industry (primarily oil and gas production), there also is port-oriented industrial activity with which manganese nodule processing and waste disposal facilities would apparently be compatible. Reynolds Aluminum's processing and waste disposal facility, located along the La Quinta Channel, is similar to the reduction facility envisioned for processing manganese nodules. Another facility, the ASARCO zinc smelter located along Corpus Christi Inner Harbor, is similar to the smelting plant that may be used in nodule processing.

It can be expected that some resistance may be encountered from farmers or oil and gas interests. However, it has generally been the case that their main concern is that they receive a fair price for their land.

While groundwater availability for plant makeup and waste slurring is unlikely, surface water should be readily available after completion of the planned Choke Canyon dam and reservoir.

Access to the Corpus Christi Inner Harbor is via the Corpus Christi Ship Channel which crosses Corpus Christi Bay. The COE authorized project depth of 14 m (45 feet)

for this channel is more than adequate for manganese nodule transport ships. The Gulf Coast Intracoastal Waterway provides access for shipments of Midwestern coal to the processing plant. The Missouri Pacific and Texas Mexican railroads also serve the port area.

Hawaii Sites

The two sites in Hawaii differ from the rest of the sites in that they have already been identified and considered as potential areas for the location of a manganese nodule processing operation. DPED has been interested in the manganese nodule mining industry for 10 years and has established a manganese nodule program. DPED has either sponsored or conducted a number of studies concerned with manganese nodules, the most recent of which is The Feasibility and Potential Impact of Manganese Nodule Processing in the Puna and Kohala Districts of Hawaii (176). The DPED report describes two scenarios at two specific areas--one in a wet climate and the other in a dry climate--for the onshore transportation, processing, and waste disposal of manganese nodules. The present report considers the two areas identified by the DPED report, with one slight deviation: the Hawaii-wet climate (Hilo) site overlaps somewhat but differs from the site presented in DPED's report. The DPED report's scenario for a wet climate site uses the Hilo harbor, but locates the processing plant further southeast of Hilo in the Puna district. The southeast portion of the site delineated in this report is within the Puna district, while the northeast portion is within the South Hilo district. Messrs. Jenkins and Keith, two of the report's authors, have indicated that the site just south of the airport, which is used in this report, is superior to the Puna site. Specifically, it is closer to the Hilo harbor; there should be fewer zoning conflicts; local officials and the public seem to prefer this site; and it is less likely that important flora habitats will be disturbed.

The Hilo site does agree with DPED's work to date, as reflected by a paper written by Messrs. Jenkins and Keith, which was presented at the Offshore Technology Conference in Houston, Texas, in May 1981 (181).

With DPED as the lead agency, the State of Hawaii has done extensive work to advance to the point where potential sites can be selected for the location of a manganese nodule processing plant. By conducting an environmental assessment of sites selected by DPED, this report provides a useful service for Hawaii; it will build on previous work to provide another analytical layer to DPED's studies. The selection of sites in areas other than those identified by DPED would be meaningless in the context of previous work. In addition, Hawaii has a small land area when compared to the areas investigated in the Gulf of Mexico and along the Pacific Coast. It is only reasonable that more specific sites can be selected with a greater degree of confidence than would be possible for the other study areas. With sites as specific as those identified by DPED, a more detailed review of relevant factors is possible.

The island of Hawaii, which is known as the Big Island, is the largest of the Hawaiian Islands, yet it is one of the least developed, particularly in terms of tourism. The island of Hawaii was selected over the other islands on the basis of a favorable combination of the following factors: (1) adequate harbors or harbors for which necessary improvements would be feasible, (2) sufficient undeveloped land close to the harbors, (3) available water and other services, (4) an adequate labor force, and (5) likely acceptance by the local public and officials. The Hawaii County government has expressed an interest in the manganese nodule processing industry and, on the State level, it is a policy to encourage economic and employment opportunities on islands other

than Oahu. Finally, there does not appear to be any significant public opposition to such a development and, at least for the present, large areas of coastal and near coastal lands without tourist developments should help to minimize resistance to the manganese nodule industry.

A brief review of limitations of other islands is in order. Maui has been experiencing strong development for tourism and it is likely that an industrial use of buildable land that is also suitable for tourist development would be met with strong resistance. Water shortage has also been a problem on Maui and upon occasion rationing has been necessary. Kahului, the only potential harbor in Maui, has a restricted entrance and it is susceptible to tsunami damage. A waterfowl refuge is on the east side of the harbor.

The Barber Point/Pearl Harbor area is the only possible harbor for manganese nodule transport ships on Oahu. However, there is virtually no available land in this area and water shortages are a growing problem on Oahu, particularly in the Honolulu area.

Substantial work would be necessary before the harbors of either Port Allen or Nawiliwili would be suitable to receive transport ships. Both ports have restricted lands around their harbors. In general, Kauai is opposed to development and it is likely that the manganese nodule processing industry would be more favorably received on the Big Island than it would on Kauai.

In summary, the selection of the Hilo and Kohala sites is based on the following points:

- (1) They are representative of Hawaii's wet and dry climates.
- (2) They have favorable characteristics in terms of the factors used to select representative sites.
- (3) They do not appear to have major flaws that could be corrected by the choice of other sites in the state.
- (4) They have been selected by DPED.

However, this report does not endorse the sites as being the best sites in Hawaii. Only a cursory review of other possible sites was conducted and a comparison of potential sites is not within the scope of this study. The important point is that these sites satisfy the requirements of being representative for mineral waste disposal in the wet and dry climates of Hawaii. Finally, it should be noted that the best location for a manganese nodule waste disposal site would obviously be close to the processing plant. Although general factors important to the selection of a plant's location were considered, this study did not apply a site selection survey for processing plants. (Nor is the DPED report a site selection survey for processing plants; rather, it presents hypothetical scenarios to illustrate the feasibility and potential impact of processing manganese nodules at two sites in Hawaii). The notion of selecting the best mineral waste disposal site is moot without the selection of a processing plant site.

Hilo Site

The Hilo site is just southeast of Hilo, the largest city on the Big Island. The northern boundary of the site runs parallel to and just south of the General Lyman (Hilo) Airport. The eastern boundary follows the coast and the western boundary roughly

follows Route 11 until it turns eastward. The southern boundary is 10 km south of and parallel to the northern boundary. The northeast portion of the site is within the South Hilo district, while the southwestern portion is within the Puna district. The South Hilo-Puna district boundary line runs from the southwest corner to the northeast corner of the site; it almost perfectly bisects the site. The site is the closest undeveloped land to the harbor of Hilo. Current uses include a National Guard armory, a sanitary landfill for Hilo, and basalt quarries. All of these uses occur near or along the western boundary of the site in the South Hilo district.

The rainfall averages between 330 and 380 cm (130 and 150 inches) per year, which is about one-half of the maximum for the wet side of Hawaii. The site lies on prehistoric basalt rock from the Mauna Loa volcano. It is relatively flat with a slope of 0-5%. It is outside of both tsunami inundation and floodprone areas. The groundwater for the site is basal water floating on salt water. There are no producing wells in the area, although there are two abandoned wells at the National Guard armory. There are indications that these wells may tap brackish water. It does not appear that development of this area will interfere with any current water supply systems.

Most of the land in the South Hilo district portion of the site is publicly owned. The Hilo Community Development Plan (adopted in 1975) (17) and The General Plan, County of Hawaii (adopted in 1975) (74), both recommend agricultural and general industrial uses for the site. The General Plan recommends orchards for the portion of the site in the Puna District, with the exception of about a 1,000-ha (4-sq mi) coastal site that is zoned for alternate urban expansion. In accordance with providing services for the industrial-zone portion of the site, The Hilo Community Development Plan recommends improved road access, an energy trade material corridor from the harbor to the site, new 16- and 10-inch water lines, and a 20-24 inch sewer line along the site's western boundary. The plan also states that the armory could be moved to provide more land for industrial uses.

Kohala Site

The dry-climate Hawaii site is located to the east and southeast of Kawaihae Harbor in South Kohala. The South Kohala district is relatively undeveloped and has a population density range of 1-10 persons per square mile. The district had a population of 2,300 in 1970 and the projected 1980 population is 4,000. Waimea, which is outside of the site, to the east, is the most populated town in South Kohala. However, development pressures, particularly along South Kohala's scenic coast, is expected to increase as resort and residential developments along the Kona Coast expand northward.

The land most suitable for waste disposal within the site is probably the area southeast of Kawaihae bounded by Highway 26 (Kawaihae-Waimea Road) to the north and Highway 19 (Kailua-Kawaihae Road) to the west. This is because the coastal land west of Highway 19 contains most of the residential development in the area, historic and archaeologic sites (including a national historic site), and a bird reserve, and it is subject to tsunami inundation and flood hazards. The area north and east of Kawaihae (north of Highway 26) has a slope of about 10-12%, about twice as steep as the land south of Highway 26.

The portion of the site south of Highway 26 and east of Highway 19 has been used for cattle grazing by the Parker Ranch. The land is privately owned except for a 2-km- (1.2-mile-) wide band of public land that runs from the coast at the southwest border of the site ENE through the site. Its slope is approximately 6%.

Physiographically, the coastal area of the site is referred to as the Kiholo lava plain and the area further inland is slightly dissected Waimea uplands. The area was formed on prehistoric lava from Mauna Kea volcano. Risk from volcanic hazards is slight; the site is located within a B zone and the nearest historic flow is an 1855 flow from Mauna Loa, about 6.5 km (4 miles) south of the site. The area receives an average annual rainfall of about 25 cm (10 inches), and all streams in the area are ephemeral. The groundwater is basal water floating on salt water and is brackish from the coast to a distance of about 4 miles inland. There are four wells in the site that are part of the area's water supply system. Two deep wells located at an elevation of 174 m (570 ft) about 3.7 km southeast of Kawaihae add brackish water (about 250 ppm chlorides) to a pipeline that runs from the Waimea treatment plant just north of and parallel to Highway 26 towards the coast. Two other wells, which are located at an elevation of 350 m (1,150 ft) about 8 km southeast of Kawaihae, provide water for a pipeline that runs west toward Puako. Proposed improvements to the water system are additional installations along the pipeline from Waimea to the coast.

The General Plan, County of Hawaii, has zoned the coastal land west of Highway 19 up to Kawaihae for residential, resort, and open area uses. The area around Kawaihae Harbor is zoned for industrial and residential uses. An alternate urban expansion zone extends east of Highway 19 along Highway 26. With the exception of a small portion of land zoned for open area use in the southern part of the site, the rest of the site area is zoned for extensive agricultural use.

PRELIMINARY ASSESSMENT OF ENVIRONMENTAL
CONSIDERATIONS RELATED TO ONSHORE
NODULE REJECT DISPOSAL

Potential Effects

For purposes of an environmental assessment of nodule reject disposal, Rogers, Golden & Halpern identified potential effects to be expected with the types of reject, the likely waste disposal techniques, and the range of site conditions selected. Sources of information were the PEIS for Deep Seabed Mining (272), previous manganese nodule environmental studies, environmental assessments for comparable facilities and for the same geographic areas, and the judgment of the study team. The effects considered in this assessment are as follows:

- o release of solid materials as fugitive dust, including wind erosion of reject solids from tailings pond and fill surfaces;
- o discharge of liquid effluent/contamination of surface waters including reservoirs;
- o migration of liquid phases of rejects from containment/aquifer contamination;
- o tailings retention structure failure with flooding and/or mass soil movements;
- o water consumption by evaporation, hydraulic transport of rejects, and dust control in water deficient areas;
- o attraction of waterfowl and other wildlife to tailings ponds;
- o impairment of present and future mining operations;
- o stockpiling of value metals, including manganese;
- o habitat creation/land reclamation;
- o displacement of or conflicts with existing and proposed land use on and adjacent to the waste disposal site;
- o displacement of or conflict with species with special status;
- o interference with historical and archaeological sites;
- o displacement of important farmlands, including prime farmland, farmland of statewide importance, and unique farmland;
- o visual conflicts including those with designated wild and scenic rivers and integral vistas of PSD Class I areas;
- o destruction or modification of wetlands;
- o modification of flood hazard areas;
- o degradation of marine habitat by surface and/or groundwater release of effluents at coastal and estuarine sites;
- o spills of rejects in transit to the disposal area;
- o noise; and
- o socioeconomic effects.

This list of potential effects was evaluated first in relation to classes of waste disposal technique and nodule process. Only effects that applied to probable combinations of waste disposal technique and type of process were considered in relation to site conditions. Sites, processes, and disposal techniques were then combined in an integrated assessment to identify the characteristics of the rejects and the conditions at each representative site that are important to the effects of disposal.

Types and Amounts of Release

Because rejects have not been produced in quantity, there exists no experience with respect to their behavior in waste containment areas of the types used for terrestrial ores. Therefore, evaluations of the possible mechanisms for the release of pollutants must also be based on analogies to experience in the containment of rejects from terrestrial mining. While potential release mechanisms can be identified, it must also be emphasized that the design of waste containment systems will be developed to reduce the likelihood of such events and to mitigate their effects should unforeseen events occur. This will be done through a combination of proper site selection and the use of engineering procedures and safeguards appropriate for the disposal area and system chosen.

The potential exists for accidental release of nodule waste materials during transport to the containment site and from the site both during and after emplacement. Accidental releases may also occur within the plant site, but emergency spill collection areas will be provided within the plant to contain material, which will then be reworked, as appropriate, following correction of the cause of the incident. For purposes of this assessment, it is convenient to establish two types of release: episodic and chronic.

Examples of episodic release include catastrophic failure of a section of the slurry pipeline transporting wastes from the plant to the disposal area, and catastrophic failure of tailings dams in the waste containment area due to overflow from floods. The primary measures taken to reduce the possibility of such releases include both engineering design and ongoing maintenance. For example, pipeline materials will be selected based on their resistance to corrosion/erosion, and wall thickness and supports will be selected to withstand both internal pressures and seismic loads. Periodic nondestructive testing can be carried out to ensure that pipeline integrity is maintained. The design of containment structures will be carried out after a thorough analysis of the types of construction materials available and loads that will be imposed. During operation, periodic inspection will be made for evidence of incipient failure such as seepage and shrinkage. Proper site selection is the primary measure taken to avoid release of materials through displacement by flood. During normal operation, routine waste pond management practices will ensure that liquid wastes are contained within the designated areas.

Should an episode occur, the potential exists for the release of very large amounts of material. Pipeline failure would be recognized almost immediately, and operation would be terminated so that no more than a few thousand tons of materials would be released. Catastrophic failure of a waste containment area could result in the release of much larger amounts of material, depending upon the nature of the failure, size of the individual area, and the properties of the waste. The largest amount of material released from failure or displaced by flooding would be water not yet decanted from ponds or wastes that had been newly deposited and not yet stabilized. Therefore, release of a rapidly settled, free-draining material such as slag is potentially much lower than for hydrous, possibly slimy rejects from four-metal hydrometallurgical processes. The normal practice is to "design around" such possibilities using established engineering approaches, and the estimated probability of such occurrences is low (96).

Examples of chronic release of wastes from disposal areas include seepage of liquids through containment structures to groundwater, percolation of liquid through the bottom of containment areas into underlying aquifers, and migration of solids from the disposal area as windblown dusts or as fugitive emissions escaping during emplacement. Slow leakage from a pipeline section or at a pumping station also could become a chronic

problem. While the amount of materials released in such incidents would be much smaller than from episodic failure, the occurrences may be harder to detect. In particular, percolation of liquids into groundwater might be undetected for long periods if monitoring wells were not properly located. As is the case for episodic releases, proper engineering design and standard operating practices and procedures are used to minimize the possibility of such occurrences.

Both solid and liquid materials may be inadvertently released from waste containment areas, but release of gaseous effluents--other than evaporated water--is not likely.

Differences in Effects Based on Classes of Waste Disposal Technique

For purposes of discussion the ten waste disposal techniques discussed in this report can be grouped into four categories:

- o above-surface retention structures,
- o specially excavated pits/backfill of mines/deep disposal,
- o "dewatered" tailings disposal (including slag), and
- o liquid waste disposal (evaporation/deep well injection).

Table 10 identifies potential effects by category of disposal technique, and the following subsections discuss the more notable effects.

Release of Fugitive Dust

Fugitive dust generation is a problem with most disposal facilities associated with mineral processing. In general, drier and windier climates are more susceptible to fugitive dust problems than wet climates, where the waste materials tend to stay saturated longer or have less area exposed to surficial drying.

For all practical purposes, slag disposal and the liquid waste disposal techniques have no problems associated with fugitive dust either in wet or dry climates. However, above-surface retention structures and to a lesser extent specially excavated pits can develop fugitive dust problems on areas exposed to wind and not covered by water. Surficial treatments such as chemical bonding agents, disking in straw or other vegetation, and covering with gravel or non-erodible material can be used to successfully reduce the fugitive dust impact. Careful management such as keeping the surface area wet at all times also helps minimize the fugitive dust problem.

Discharge of Liquid Effluent to Surface Water and Groundwater

Control techniques such as clay- or membrane-lined retention structures and evaporation ponds have been developed to minimize the discharge of liquid effluent. However, any structure built above grade has the potential for discharge of liquid effluents through seepage or accident. The most catastrophic discharge would be if a retention embankment or dike failed. The chance of this happening is low for properly engineered structures. Safe retention embankments can be constructed in almost any area as long as the design accounts for site conditions. In earthquake-prone areas,

TABLE 10. - Potential effects for different classes of waste disposal technique

Potential effect	Above-surface retention structures	Specially excavated pits/backfill mines/ deep disposal	Dewatered tailings and slag	Liquid waste disposal
Fugitive dust.....	PP--can be controlled by careful management of disposal facility	PP for pits and surface mines--can be controlled--NP for underground disposal	NP for slag--PP for dewatered tailings--can be controlled	NAP
Surface water contamination.....	PP	NP since disposal is below grade	MP	PP for evaporation pond
Aquifer contamination..	PP--lined reservoir may be required	PP--disposal usually above water table--lined pit or mine may be required	MP for slags; PP for dewatered tailings in wet climate	PP--lined pond may be required
Retention structure failure.....	PP	NP	MP	PP for evaporation ponds
Water consumption.....	PP	MP--small surface area	NP	NAP
Attraction of wildlife.....	PP	MP	NP	PP
Impairment of mining operations.....	MP	NP	NP	MP for ponds NP for wells
Stockpiling of value metals.....	NP	PP for deep disposal	NP	NP
Land reclamation.....	Potential reduction of land value	Beneficial--reclaim mine areas	Beneficial for structural fill, probable increase of land value	Potential temporary reduction in land value
Conflicts with land use.....	PP--least desirable of disposal methods	Possibly beneficial as a means to reclaim a mine area	NP because of beneficial uses for slag	PP short-term

Displacement of important farmlands..	do.	PP--specially excavated pits--NP for mines	do.	do.
Conflicts with species with special status..	PP	NP in mines--PP for specially excavated pits	PP	PP for evaporation ponds--NP for deep well
Interference with historical/archaeological sites.....	PP	do.	PP	do.
Visual conflicts.....	PP	do.	PP	do.
Modification of wetlands.....	PP	do.	PP	do.
Modification of flood hazard areas.....	PP	PP	Small potential for significant modification	do.
Degradation of marine habitat.....	PP	NP	PP	do.
Spills of rejects in transit.....	MP	MP	MP	MP
Noise.....	Temporary--limited to construction	same as left	same as left	same as left
Socioeconomic effects..	PP	Possibly beneficial if land value is increased by filling old mines	Possibly beneficial if land value is increased by placing slag as structural fill	PP

NAP Not applicable.

PP - Potential problem. Site conditions and waste disposal plan specifics would have to be evaluated to assess significance of the effect.

MP - Minimal problem. The effect is not expected to be significant except under highly unusual circumstances.

NP - No problem. The effect is not expected to occur for this waste disposal option.

special design precautions such as flatter slopes, thicker drains, and denser compaction would have to be taken to compensate for the dynamic loading conditions that occur during earthquakes.

The fine-grained texture of the hydrometallurgical wastes and the severity of the problem associated with a catastrophic failure are the principal reasons why these materials probably cannot be used for tailings dam construction as is common in the mineral processing industry.

Below-grade structures prevent the possibility of flow or contamination of surrounding areas by the tailings and also provide more secure protection against the effects of long-term erosion. However, they usually must provide for groundwater and leakage control.

Evaporative Water Losses and Water Losses through Consumptive Use

In water deficient areas (that is, dry climates as opposed to wet climates) it is often desirable or necessary to recycle as much water as possible. Water losses from large reservoir surfaces or water consumption for such things as dust control and hydraulic transport of tailings can be a major consideration in these areas. For instance, the requirement to control fugitive dust, as discussed previously, conflicts with minimizing the use of water. Therefore, thickened slurries or chemical treatment of the tailings surface may be required to minimize water losses. The consideration of water losses would normally be greatest for above-surface retention structures, would be less for specially excavated pits and mine backfills where the surface areas normally are reduced, and would not be a problem at all for dewatered tailings and slag disposal.

Attraction of Waterfowl and Other Wildlife to Tailings Disposal Areas

The attraction of wildlife, including waterfowl, to tailings disposal areas is common and is not necessarily a problem unless the tailings effluent is toxic or otherwise harmful to the wildlife. The surface retention facilities and the evaporation ponds are the most likely to attract wildlife and waterfowl.

If the effluent is toxic, control measures such as fences, noise cannons, and screens can be installed, although these are not always effective.

Stockpiling of Metals, Including Manganese

With the possible exception of disposal in deep mines, the disposal techniques considered in this study all would provide easy future access to the waste material if value metals were to be extracted at a later date. Even disposal in a deep mine would not necessarily be a problem, although the extraction procedures may be more complicated and more expensive than from shallow burial or surface facilities.

Habitat Creation and Land Reclamation

The disposal techniques involving backfilling of pits and disposal of dewatered tailings or slag actually could provide beneficial uses in terms of land reclamation and possibly habitat creation. For example, slag from the smelter in Tacoma, Washington, is presently being used for breakwater construction and landfilling and as such is quite valuable to the local area.

Landfilling using dewatered tailings could also provide beneficial uses in marginal areas where the land could be built up to provide a base for commercial/industrial or recreation facilities. However, surface retention facilities containing a slurry and evaporation ponds are unlikely to provide any type of beneficial use. In fact, in most cases, the value of the land covered by these disposal facilities would probably be decreased in both the short and long term.

Conflicts with Existing and Proposed Land Use

Before selecting a slurry tailings disposal site (and to a lesser extent a slag disposal site), it will be necessary to determine the land use of the area and to evaluate the appropriateness of utilizing the land for tailings disposal. In densely populated areas such as Southern California and some areas along Puget Sound and the Gulf Coast, it may be very difficult to locate sites for surface retention facilities near the coast because of competing and conflicting interests for the land.

Displacement of or Conflict with Species with Special Status

For all disposal techniques there is the potential problem of interfering with the habitat for species of wildlife with special status. A major siting concern would be avoiding areas where conflicts of this type could occur. Disposal in surface and deep mines would probably present the fewest problems in this regard since disturbance at these sites would have already taken place.

Interference with Historical and Archaeological Sites

As with interference with species with special status, it will be necessary to avoid locating the disposal facilities in areas of historical importance. It would be difficult to site any of the disposal facilities in an area of historical or archaeological significance unless the facility were in an area that had already been disturbed by, for example, a mine or quarry.

Conflict with Scenic Areas

All of the disposal methods with the exception of disposal in mines will involve substantial disruption of the surface area during the time disposal is actively taking place and to a lesser degree after reclamation has been completed. Therefore, most of the disposal methods could conflict with scenic areas. The siting process would require locating waste disposal facilities where minimal scenic impact would take place and/or using a below-grade technique which might have less visual impact.

Modification of Flood Hazard Areas

One of the primary concerns in the siting process is finding a site that is away from designated flood hazard areas. However, containments will be partially located in floodplain areas when using a cross-valley dam. In this case the dam will retain water from the upstream watershed and thereby modify downstream flood hazard areas. Sidehill dams may in some cases also interrupt upstream drainage and reduce flood peaks.

Flooding and subsequent erosion of a disposal facility is one of the principal means by which releases of liquids or solids can occur. Also, floodprone areas are difficult to reclaim, particularly with respect to long-term protection after closure.

Spills of Rejects in Transit to the Disposal Area

Presumably the slurry materials will be transported in a pipeline as is conventional in the minerals processing industry. While breaks in pipelines do occur, these can be minimized by careful maintenance of the pipe. In critical areas the pipeline can be buried to prevent a pipe rupture from spreading over adjacent land.

Slag is often handled by conveyors, trucks, or rail cars, and the same would be true for dewatered tailings. A potential for accidents exists with transporting dry waste materials, but the volumes involved are generally small and any spills would be limited to a small area.

Socioeconomic Effects

All of the disposal methods have the potential to reduce adjacent real estate values, particularly if the adjacent land has not already been disturbed by a similar type of heavy industrial activity. The possible exception to this is backfilling of surface mines where the actual value of the land would be upgraded by the disposal facility. Also, slag carried off site or used on site for structural fill could create a situation where the value of the land is increased.

Summary

In summary, the disposal of dewatered tailings or slag would probably be the least difficult from the regulatory and siting point of view because of fewer identified problems and potential for beneficial uses.

On the other hand, above-grade slurry disposal facilities and evaporation ponds would probably be the most difficult to site and obtain permits to operate. Coastal areas often have sensitive environmental problems, are heavily populated, and have competing land uses, which would make siting a tailings disposal facility difficult.

Disposal in specially excavated pits, backfilling surface mines, or deep mine disposal could be easier from a regulatory standpoint than surface facilities. However, the probability of finding the latter two types of facilities near most port areas is fairly low. Deep well injection is a special category of liquid disposal where, by definition, the liquids are disposed of in an aquifer that is already considered contaminated or

nonusable. Therefore, minimal problems are associated with this type of disposal other than locating a site where the disposal can occur.

The relative problems associated with wet or dry climates are primarily operational considerations. Historically, most tailings disposal operations have been in drier climates, and the technology favors this. However, in the Southeastern United States, particularly Florida, slurry disposal (for phosphates) is successful in a wet climate. Extremely wet climates where evaporation of effluent is not possible and where the tailings surface would never dry out would present special problems for slurry wastes. On the other hand, dewatered tailings and slag could be handled well in a wet or dry situation.

Differences in Effects Based on Classes of Process

Three classes of process wastes and one subclass have been considered in the environmental assessment: (1) leached tails from three-metal hydrometallurgical processes (subclass--residues from these processes with some manganese removed); (2) leached tails from four-metal hydrometallurgical processes and residues from electrolytic manganese reduction that are not slags; and (3) slags from smelting processes and from manganese recovery from three-metal tailings.

These classes of waste are closely related to the disposal techniques. Although landfill methods can be used for dewatered hydrometallurgical process tailings, they are primarily associated with slags. Likewise, above-grade retention structures are primarily used for slurried hydrometallurgical process wastes because slags do not require a containment. Deep disposal applies to all of the processes and liquid disposal applies to liquid wastes from any process.

Because of the link between the processes and the disposal techniques, many of the entries in table 10 for above-surface retention structures apply to slurried hydrometallurgical process wastes as well, and those for dewatered tailings and slag disposal apply to slags. Therefore, this discussion emphasizes the differences in effects between three-metal and four-metal hydrometallurgical processes and differences between hydrometallurgical wastes and slags that are not brought out in the table and the discussion for waste disposal techniques.

Differences in effects based on the class of process are related to the amount of waste and its settled density and the texture of the rejects and their drainage characteristics. Effects are also related to chemical characteristics of the rejects, but, other than the basic distinction that slags are typically inert and that the slurried wastes are possibly toxic, no meaningful distinctions regarding effects based on chemical properties can be made without data from testing of process rejects.

The relative magnitude of effects that depend on the area of the disposal site for the rejects is indicated by their settled volume. Accordingly, land use conflicts, displacement of farmlands, visual conflicts, and modification of wetlands and flood hazard areas, where they are relevant concerns, will vary with the volume of waste. From the data in table 6 and for similar terrain, three-metal hydrometallurgical processes would require substantially more land area than four-metal hydrometallurgical processes, even adjusting for differences in the nodule processing rates. Four-metal hydrometallurgical process wastes would apparently require less land area than smelting slags, however, the volume and area occupied by the containment structure would also have to be included for a hydrometallurgical process.

Fugitive dust emissions and aquifer contamination potential vary with the (nonsubmerged) surface area and the bottom area of the containment, respectively, and therefore also with the volume of waste. For slag disposal, since these effects are not a problem, differences in surface area are not significant.

Remaining effects such as retention structure failure and attraction of or conflicts with wildlife have less direct relationships to area and volume. A retention structure will typically be more prone to failure the higher it is and the more embankment it has, however, other characteristics of the waste (such as drainage) and the site conditions and embankment design can offset these factors. The construction of a large retention structure will eliminate more wildlife habitat than the construction of a small structure. Similarly, once the facility is in operation a large pond could be expected to attract a greater number of waterfowl than would a small pond at the same site. In addition, a large pond would tend to attract large flocks of waterfowl that would use it for rafting during spring and fall migration whereas a small pond might not attract migrating waterfowl.

The texture of the rejects indicates general susceptibility to wind erosion. Four-metal hydrometallurgical process rejects are expected to be finer grained and to be marginally more susceptible to wind erosion and fugitive dust impacts. However, without a detailed grain size distribution the difference between processes could not be quantified. The texture also influences how the wastes dry so that if the four-metal rejects are more prone to retain water this may partially offset differences in texture.

The potential for contamination of surface waters partially depends on the drainage characteristics of the rejects. Surface water contamination is not a real problem for slags because they drain rapidly and freely enough that the liquid wastes will not have to be stored in a large pond. Three-metal hydrometallurgical processes have a potential for greater effects than four-metal because there is more liquid and more of it would be squeezed out as the rejects settle. Excess liquids that are decanted but cannot be recycled could be disposed of in evaporation ponds or by evaporation from the tailings pond. For evaporation ponds the volume of excess liquids and the corresponding surface area indicate the risk to groundwater from chronic releases and the amount of liquid indicates the exposure to surface waters from a catastrophic release.

For catastrophic releases of waste material from events such as retention structure failures, it is not possible to estimate the difference in effects between three-metal and four-metal hydrometallurgical process tailings at this time. The amount of material released would depend on the size and shape of the dam break, the amount of free water above the break and the angle of repose of the slurried waste as well as the amount of waste within the containment.

A distinction based on the classes of process waste for disposal as dewatered tailings or slags should also be made. While the slags are inert because of their vitreous composition, dewatered hydrometallurgical tailings are not really inert but rather the leaching of soluble components is limited by removing free-water and restricting infiltration of precipitation. In very wet climates, despite efforts to preclude it, water may be added to the rejects in the containment and may remobilize soluble components of the dewatered rejects.

Important Site Conditions

The potential effects that have been discussed above as they are affected by differences in processes and disposal techniques are also affected by site conditions. The chances of various effects occurring and their relative significance depend on whether the site has certain features present. For example, adverse effects on endangered species can only be expected if the site has habitats that could support the species, even if there are none there now. A value judgment would have to be made as to whether a suitable habitat has ever existed on the site or if it could be created. In fact, sites will typically be chosen to avoid negative effects where possible. However, even assuming that the sites chosen for a waste disposal facility are among the best sites available, there will still be some effects that occur because they are inherently part of the facility or inherently part of the region in which the facility is located.

The site conditions that are typically most significant to onshore waste disposal are biophysical characteristics such as terrain, groundwater use and quality, geologic protection of groundwater, wildlife habitats and climate; and sociocultural characteristics such as land use and ownership. In discussing important conditions that influence the effects of disposal at each representative site we have organized the description of each site under the headings "Biophysical Characteristics" and "Sociocultural Characteristics." The site discussions that immediately follow present only the basic considerations for geologic, soil, and climate characteristics, while most of the details of these characteristics are presented in Appendix B.

Cherry Point, Washington: Pacific Northwest Representative Site

Biophysical Characteristics

The Cherry Point site (figure 11) is located near the shoreline along the Strait of Georgia in the Puget Sound area of northwestern Washington. The northwestern corner of the site touches Birch Bay, and the southwestern edge of the site from above Cherry Point to Neptune Beach has frontage on the Sound.

The site is in the Puget Trough or Puget Lowland, a sharp contrast to the Northern Cascades to the east, which dominate the area from a physiographic standpoint. Mount Baker in the Northern Cascades is visible in the distance from several viewpoints oriented primarily along east-west roads. Maximum elevations within this part of the Puget Trough are about 100 meters while within 20-30 km east and southeast of the site, mountains such as Sumas Mountain and Lookout Mountain rise to 800-1000 m.

The maximum elevation on the site is about 100 m (330 feet) near Holman Hill in its northeastern part. Elevations typically increase from 25 m at the coast to 100 m in the northeast quarter of the site and then decrease again to less than 25 m at California Creek in the northeast corner of the site. The maximum slope over one kilometer is 6.5% but the average slopes on most of the site are considerably less. Small strips along the coast exceed 15% slope. Many potential disposal areas 1-2 kilometers square with local relief less than 25 m are available within the 10-km square site area.

The geology of the site is primarily unconsolidated sediments derived from glacial activity--Bellingham drift overlain in parts by sand and gravel.

Most of the better groundwater aquifers in the vicinity of the site are in recessional outwash and sediments deposited prior to the most recent glaciation. Water levels are typically less than 30 m (100 feet) below the surface in shallow and deep aquifers. The typical range of well yields near the site is 0 to 10 gal/min. Till areas within the site are normally less than 10 m thick and composed largely of fine materials. They do not contain important aquifers but can transmit large quantities of water to underlying aquifers over extensive areas and thus act as recharge areas.

From an engineering standpoint, Bellingham drift has low permeability, a high response to seismic shaking, poor to fair foundation stability and low strength when saturated (92). It is also difficult to excavate when wet.

Sand, gravel, till and terrace deposits near the site should provide suitable construction material so that the real concern is the support provided by the Bellingham drift.

The Puget Lowland is in seismic risk zone 3, which means that major destructive earthquakes may occur. The bedrock underlying the area apparently consists of several blocks that may have moved vertically relative to one another. The concentration of seismic activity in the Puget Lowland suggests that the faults bordering these blocks are currently active. Shaking of the ground during an earthquake is likely to be most amplified in lowland areas underlain by unconsolidated deposits. The sands and gravels overlying the Bellingham drift have a more moderate response to shaking.

Other than small sand and gravel enterprises near Ferndale there are no mining enterprises in the vicinity of the site (224). No major mineral occurrences have been

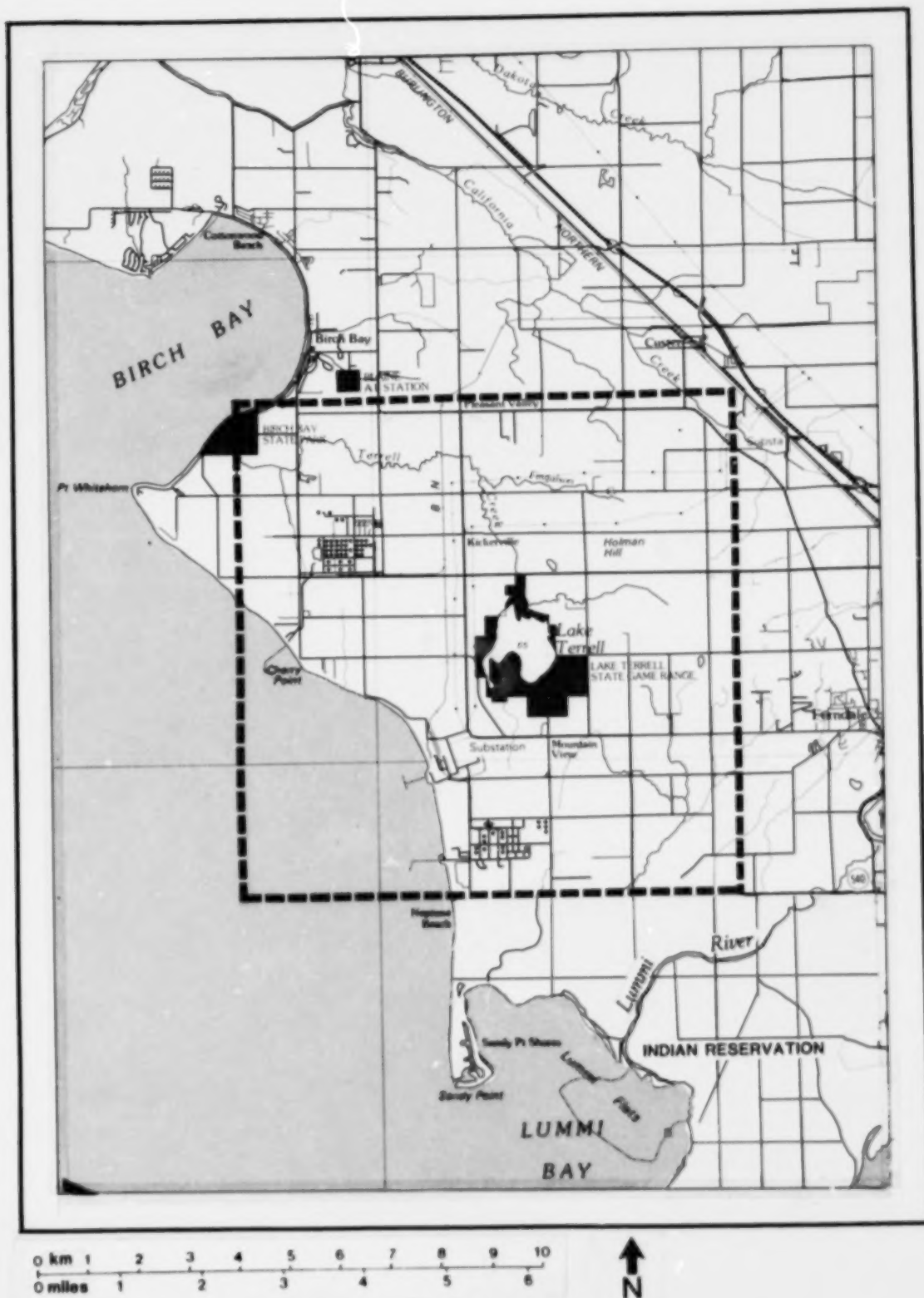


FIGURE II. - The representative site for the Pacific Northwest siting region near Cherry Point, Whatcom County, Washington.



FIGURE 12. - Representative terrain of the Pacific Northwest siting region, with a view of Mount Baker.

identified on the site; however, the site vicinity is thought favorable for oil and gas and exploratory wells have been drilled on the site (235).

The site is within the Nooksack-Sumas drainage basin. Surface runoff on the site drains as follows: Lake Terrell and most of the northern half of the site via Terrell Creek to Birch Bay; the southern part of the site via tributaries of the Lummi River to Lummi Bay to the south; coastal areas directly to the shoreline; the northeast corner to California Creek and north to Drayton Harbor. There are no major rivers or streams crossing the site and no real situations that would warrant a cross-valley dam. The streams that are on the site have their origins on the site so that no drainage area larger than about 50 sq km occurs on the site and waste disposal sites could be located that drain only 1-2 sq km.

The 100-year rainfall intensities that could be expected for the site are about 2.5 cm (1 inch) in one hour and 4.8 cm (1.9 inches) in 6 hours. Durations longer than 6 hours would not contribute to peak flows. The balance between precipitation and evaporation for the site varies throughout the year although on a net annual basis there is about 40 cm (16 inches) more precipitation than lake evaporation.

Biologically there are important wildlife areas within the site and its vicinity. Lummi Bay and Birch Bay are overwintering areas for shorebirds such as sandpipers and rails; waterfowl such as loons, grebes, swans, geese, dabbling ducks, sea ducks, mergansers, American widgeon, pintail and mallards and seabirds such as cormorants and alcids. These bays are also overwintering areas for heron and support adult concentrations of great blue heron. The Lake Terrell State Game Range and Birch Bay

State Park provide protected areas, which attract wildlife within the site. Lake Terrell particularly provides a 280-ha (700-acre) reservoir for waterfowl. There also are protected areas in conjunction with the Mobil refinery near Neptune Beach.

Critical biological areas for Pacific herring occur offshore near Point Whitehorn and a northern bald eagle nest occurs near the Mobil refinery.

Offshore along Cherry Point are spawning, nursery and adult Dungeness crab areas as well as spawning and fishing areas. Parts of this area were posted for no shell fishing in the spring of 1981. Intertidal hard shell clams are found north of Cherry Point. The shoreline along Cherry Point supports eelgrass and kelp beds as well as salt marshes and thus provides a variety of aquatic habitats.

Sociocultural Characteristics

The site and its vicinity have a complex variety of interspersed land uses. Industrial uses include two refineries and an aluminum products plant, all coastally located. Parks and natural areas are a major land use on the site. The Lummi Indian Reservation forms the entire southern border of the site and occupies the Lummi Peninsula and surrounds Lummi Bay. Residential areas are primarily water-oriented at Neptune Beach and outgrowths of Ferndale, which is the population center nearest the site. Agriculture, primarily dairy farming, is the predominant land use on the remainder of the site. Miscellaneous uses include a small landfilling operation and a small resource recovery facility.

Infrastructure is available because of the refineries. Burlington Northern has rail service to the INTALCO plant and transmission lines also serve this facility from a substation near Interstate 5 northwest of Ferndale. Rail service is oriented to coastal locations and the rail line runs close to and west of the Lake Terrell game range. A new sewer line is being constructed near the Mobil refinery. A coal export terminal is proposed at Cherry Point.

The general area focuses on Bellingham as a major population center with Bellingham Airport and Interstate 5 providing the important transportation links.

Casmalia: Southern California Representative Site

Biophysical Characteristics

The Casmalia site (figure 13) lies primarily in the Southern Coast Range physiographic province, which, in the southern portion, is characterized by three mountain ranges that lie between the coast and the San Joaquin Valley and roughly parallel to them. Lying between the site and the San Joaquin Valley are the Sierra Madre, Caliente, and Temblor mountain ranges. They are formed by folding and faulting of mostly Miocene strata. Just south of the site is the Transverse Range, which runs east-west, perpendicular to the Southern Coast Ranges. These complex mountains have steep folds that are generally aligned to major faults and broken by numerous secondary fractures. The site has characteristics similar to both physiographic provinces. The Casmalia Hills run neither parallel nor perpendicular to the coast but in between, in a northwest-southeast direction.

The elevation within the site ranges from about 30 m (100 ft) to a little over 450 m (1,500 ft). The southwest and northeast portions of the site are relatively flat while a northwest-southeast diagonal band through the site, which includes Casmalia Hills, has the steepest slopes (figure 14). Slopes in Casmalia Hills usually exceed 20% and in some areas they exceed 30%. However, a square kilometer disposal site with about a 16% slope could be located in the Hills. The elevation difference over a kilometer would be 160 m (525 feet). One-square kilometer sites with slopes of about 5% could be located in the northeast portion of the site, and even gentler slopes are present in the southwest corner of the site, although the sandy soils are unsuitable for a disposal site. The elevation difference over a kilometer with a 5% slope would be 50 m (160 feet).

The complex geology of the site, which contains 11 geologic units, is largely a consequence of displacement caused by faults. The dominant Sisquoc formation runs diagonally northeast to southwest through the middle of the site and underlies the Casmalia Hills. The Casmalia Hills are composed of consolidated marine sedimentary rocks that are essentially not water bearing.

Two earthquake epicenters of magnitudes between 4.0 and 4.9 on the Richter scale have been recorded along the site's borders. A major earthquake with a magnitude in the range of 7.0 to 7.9 has occurred just offshore from Point Sal. The dangers associated with earthquake shaking are present for the site and surrounding areas. From historic records, the maximum expected earthquake intensity on the site is VII or VIII as measured on the Modified Mercalli Scale of 1931 (337). The intensity varies with distance from the epicenter. An earthquake of Modified Mercalli Intensity VIII at the epicenter corresponds to a Richter magnitude of 6.0-6.5.

Except for sandy areas, the soils on the site are moderately expansive; that is, they tend to somewhat absorb water and swell. With heavy rains the steep slopes in the Casmalia Hills areas are subject to moderate landslide activity. Surface erosion in Casmalia Hills is also moderate (32-127 cu m/ha/yr soil loss). Possible landslides and erosion potential are slight and non-existent respectively for all other areas of the site.

In the west and southwestern portions of the site the soils support chaparral communities of low, dense coastal sagebrush composed of California sagebrush, white sage, and black sage. Low southern oaks are found at higher elevations and further inland. Some Bishop pines and coast live oaks, which are native to California, may also be found in the central and eastern parts of the site.

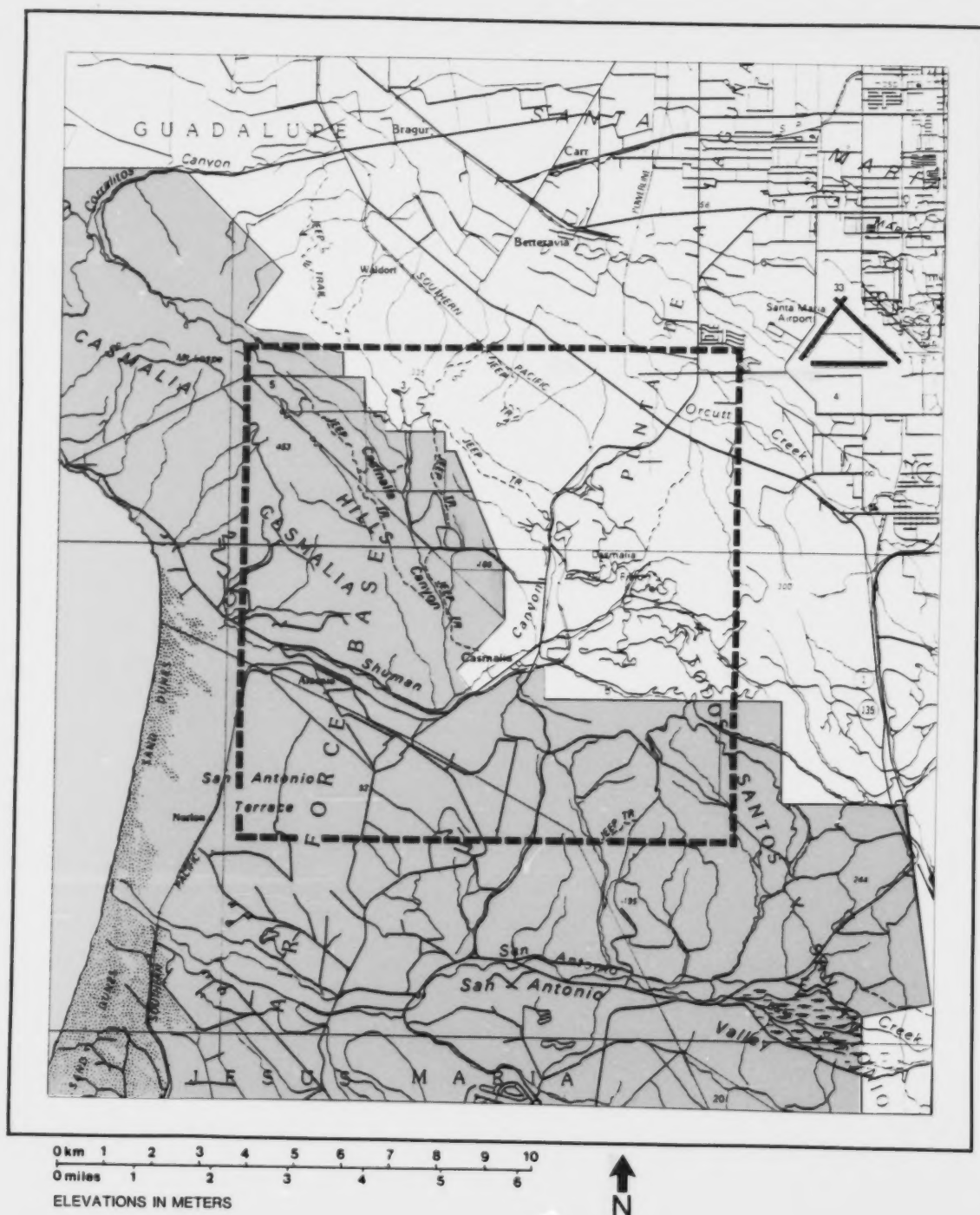


FIGURE 13. - The representative site for the Southern California siting region near Casmalia, Santa Barbara County.



FIGURE 14. - Representative terrain of the Southern California siting region, with a view of an industrial facility in the Casmalia Hills.

The site's climate is semi-arid: dry and sunny. Average yearly precipitation is 31 cm (12.25 inches). Average pan evaporation is about 202 cm/yr. Evaporation during the summer greatly exceeds winter evaporation; average pan evaporation for June is 34 cm and the average for January is 4 cm. Average wind speed is 7 mi/hr.

The northwest corner of Santa Barbara County, which contains the site, is a non-attainment area for TSP and photochemical oxidants. The Santa Maria weather station's records indicate that TSP are in the range of 100-124 $\mu\text{g}/\text{cu m}$. However, representatives from the area are petitioning EPA to reconsider the non-attainment status for the area on the basis that most of the particulates are from agricultural sources and are relatively large (larger than thoracic particulates) in size; therefore, the adverse health effects are much less than for smaller particulates (324).

Most of the site's surface water is drained by the creek that flows through Shuman Canyon. Casmalia Canyon cuts through the center of the site on a north-south axis and it drains into Shuman Canyon which forms a horseshoe bend through the center of the site. These canyons drain most of the portion of Casmalia Hills that is on the site. The stream through Shuman Canyon flows directly to the sea. The Santa Barbara County Plan Environmental Resource Management Element (360) lists the canyon's potential for flood hazard as unknown. The Orcutt stream flows through the northeast corner of the site and tributaries of San Antonio Creek flow through the southeast portion of the site. Due to the small amount of rainfall, stream flow volumes are low.

Sociocultural Characteristics

The northeast portion of the Casmalia site is located in a hilly rural setting with mineral resource developments and agriculture areas while the southwest portion is within the boundaries of the Vandenberg Air Force Base (AFB), parts of which account for about 60 percent of the site's area. The town of Casmalia is located just south of the site's center. A special census in 1975 indicated that the town's population was 188. The site area has a population density of less than two people per sq km. A mile and a half northeast of the town of Casmalia are the Casmalia oil fields, and the Casmalia Hazardous Waste Disposal Facility is about 3 km (2 miles) north of the town. The waste disposal facility covers 1,200 ha (3,000 acres), although only 72 ha (180 acres) have been used. New permits must be obtained every time additional land is to be used for disposing wastes. Large open mines for diatomaceous earth are found a few miles north-northeast of Casmalia in the hills. Most of the area in the Casmalia Hills, particularly in the northwest part of the site, is undeveloped with few roads. Some of this area is used for grazing. The portion of Vandenberg AFB within the site's boundaries is also mostly undeveloped.

The land use element of Santa Barbara County's Comprehensive Plan classifies the land outside of Vandenberg AFB, with the exception of the town of Casmalia, mining sites, oil fields and the waste disposal facility, as agricultural with a minimum parcel size of 16 ha (40 acres). The plan recommends that the Vandenberg AFB land within the site's boundaries be classified as a scientific preserve because most of the land contains relatively undisturbed plant and animal communities. However, Vandenberg AFB has no legal obligation to the plan's recommendations because it is under Federal, not the county's, jurisdiction.

The city of Santa Maria, through which Interstate 101 runs, is next to the site's northeast corner and the Santa Maria airport is just outside of the site's boundaries. The Southern Pacific Railroad enters the site from the southwest, runs through the town of Casmalia, and leaves the site at the middle of its northern boundary. The San Rafael Wilderness, which is designated as a Class I air quality area, is about 40 miles to the east, in the Los Padres National Forest.

The coast is about 1.5 miles from the site's western boundary and Point Sal is about 4.5 miles from the northwest corner. The coastal areas adjacent to the site are a part of Vandenberg AFB. A state park is located at Point Sal.

The California Coastal Management Program's Coastal Zone extends from the coast inland about 2 km (3 miles) at the southern part of the site where there are sand dunes. As the coastline becomes rocky further north, the coastal zone only extends inland about 600 m (2,000 feet). The coastal zone is only within the southern half of the site's western boundary.

A review of plans, reports, and atlases revealed no other specially recognized areas of environmental or sociocultural significance are found within the site (48, 56, 86, 231, 262, 360, 398, 423, 424, 434).

Corpus Christi, Texas: Gulf Coast Representative Site

Biophysical Characteristics

The Corpus Christi site (figure 15) lies between Robstown and the Corpus Christi International Airport, straddling Route 44. The site is generally flat, with an average grade of less than 0.9 m/km (5 ft/mi). Oso Creek flows through the site in a southeasterly direction.

The geology of the site is fluvial-deltaic deposits consisting of interdistributary muds and fluvial sands and silts (see appendix B). The engineering characteristics of the site are important particularly in terms of suitability of materials for embankment construction. The muds that predominate on the site while being excellent in terms of leachate control, are generally considered unsatisfactory for earthen structures (37). The sands and silts that make up about one third of the site area are considered satisfactory for this purpose (37).

There are no major geologic hazards associated with the site. There is no reasonable expectancy of earthquake damage along the Texas Gulf Coast (5). The only active fault located on the site is in the Saxet Oil field near Clarkwood. The limited subsidence associated with this fault is thought to be caused by natural gas production in the oil field (463). Other lineations that have been mapped in the Corpus Christi area show no evidence of active movement.

Hurricanes are a form of natural hazard that must be considered for the Corpus Christi site. While the site is far enough inland not to be affected by the storm surge, flooding along Oso Creek and high winds and rainfall may present a problem (41). However, proper containment design can compensate for these effects.

The natural vegetation of the Corpus Christi area is prairie grasses. However, most of the site is in dry cropland. The cropland is not irrigated because of the semiarid climate and relatively low water availability.

The site is not known to harbor any endangered species. The species that are endangered along the Texas coast are primarily associated with water bodies, such as the brown pelican and the manatee, or are wide ranging, such as the bald eagle and the peregrine falcon.

The climate of the southern part of Nueces County, where the site is located, is semi-arid, with annual precipitation ranging from 70-75 cm (28-30 inches). Average annual lake evaporation is about 150 cm (60 inches) (84). This creates a favorable situation for drying of wastes. In every month except September, lake evaporation exceeds precipitation, with May to August being the driest months. The net evaporation for the area is evidenced in the relative sparsity of coastal vegetation cover when compared to coastal areas further east (37).

Winds in the Corpus Christi area generally come from the southeast or the north. Persistent southeasterly winds dominate from March through September, while northerlies dominate from October through February (37). Agricultural Research Service data indicate that Corpus Christi is an area of high wind erosion potential.

While air quality on the site does not exceed the NAAQS, the port area is a non-attainment area for particulates. Particulates are the pollutant of concern for

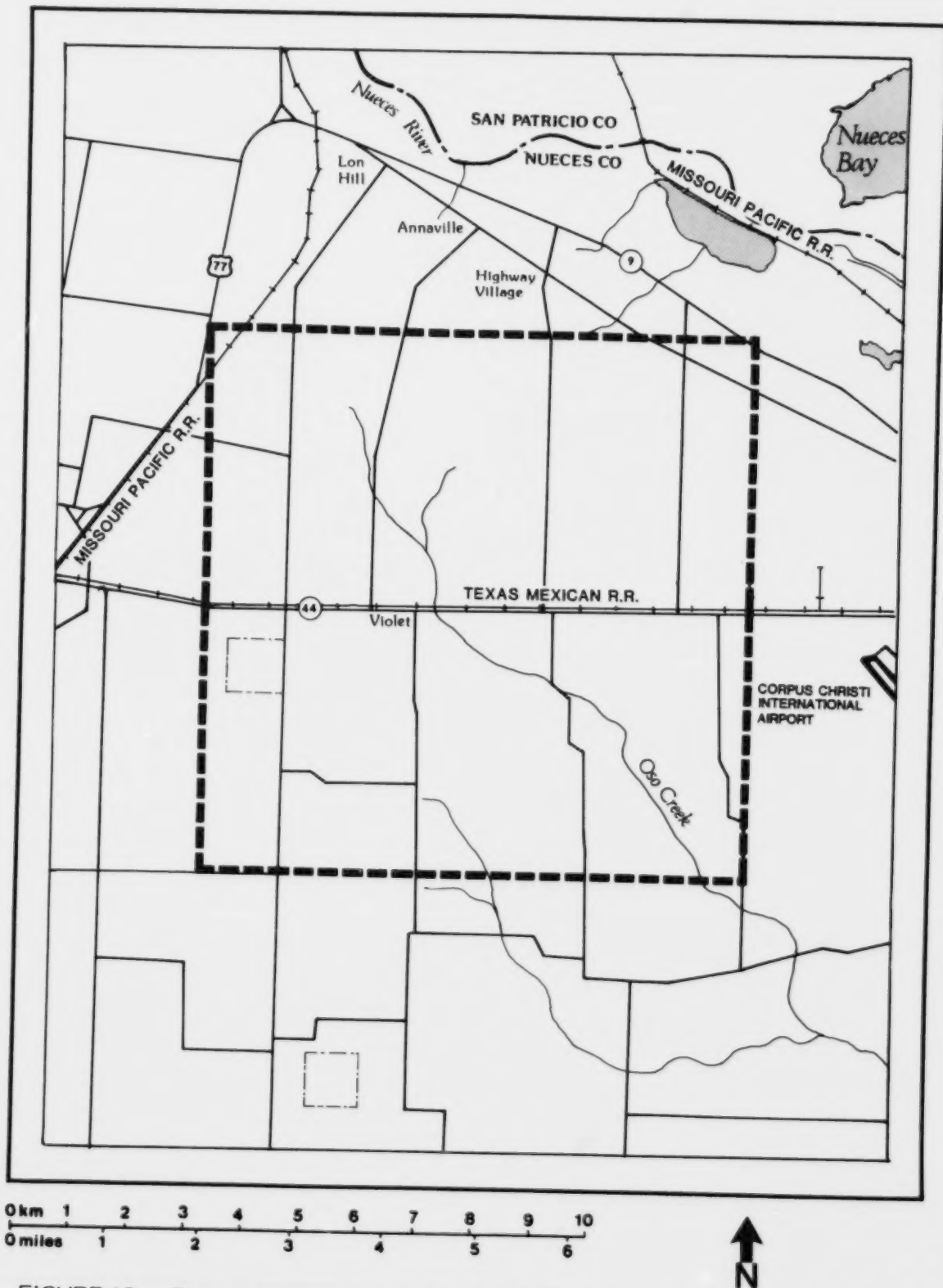


FIGURE 15. - The representative site for the Gulf of Mexico siting region west of Corpus Christi, Nueces County, Texas.

manganese nodule reject disposal and, with this site's dry climate and wind conditions, there could be a problem preventing particles from becoming airborne.

The hydrology of the area is closely linked with the surficial geology. The deltaic mud deposits have low permeability and do not generally contribute to recharge of the groundwater. The highly permeable fluvial sands and silts, on the other hand, constitute shallow (less than 75 m (250 ft)) unconfined aquifers, which are recharged locally. Because they are widely dispersed among broad areas of mud and because the rainfall is relatively low, these aquifers contain only small amounts of water. The water in the shallow aquifers in Nueces County is slightly saline ranging from 1,097-2,550 mg/l TDS (463). Deeper artesian aquifers contain large quantities of water. However, the recent trend in Nueces County is that groundwater withdrawal from these artesian aquifers exceeds recharge, so water is being taken from storage. In the vicinity of the site these sands contain water with greater than 3,000 mg/l TDS, making further development unadvisable (463).

Areas of the site subject to flooding are along Oso Creek and in several topographic depressions concentrated principally south of Route 44. These areas have poor waste disposal capacity.

Sociocultural Characteristics

The economy of the Corpus Christi area is largely based on oil and gas production, agriculture, commercial fishing, and a growing tourist industry. The area outside the city limits is predominately agricultural, with industry centered around the ports. However, some industry, such as the Corpus Christi Petrochemical Plant, is located away from the port in a predominately agricultural area. Most of the site is in cropland, the primary crops in the area being milo and cotton. There are small areas of mixed commercial and residential uses, notably at Violet and Clarkwood. Part of the site is an oil field. Oil field development often occurs in the agricultural area and it is a common sight to see operating oil pumps in the middle of cultivated farm fields (figure 16). While most of the land on the site is not developed, considerable competition for the land can be expected from the farming community and oil interests.

Location of industry in the extraterritorial jurisdiction outside the city limits offers tax advantages. The petrochemical plant on the site is taking advantage of this favorable tax situation.

Highway access in the site is good. Several main roads cross the site. The Texas Mexican Railroad parallels Route 44, and they both run through the center of the site.

Environmental concerns on the site will probably be related to these conflicting uses rather than to biophysical concerns such as habitat destruction. Possible contamination of shallow aquifers developed for rural and livestock uses will probably also be of concern. The site does not contain any wildlife management areas, parks, or recreation areas; most such areas are situated closer to the coast. There are no wild or scenic rivers in the Corpus Christi area.



FIGURE 16. - Representative terrain of the Gulf of Mexico siting region, with a view of an oil pumping operation.

Hilo: Hawaii Wet Climate Representative Site

Biophysical Characteristics

The Hilo site (figure 17) is flat, rocky, and covered with vegetation interspersed with bare areas (figure 18). Physiographically, most of the area is referred to as the Hilo lava plain, which has a slope of 0-5%. There is a transition to the Mauna Loa undissected upland in the southwestern corner of the site where the slope increases. The highest elevation on the site, about 120 m, is found at this southwest corner. However, the land rises gradually throughout the rest of the site. The elevation directly south of the airport is 20 m, and this elevation contour runs roughly southeast through the site. The elevation at the center of the site is about 25 m. If a square kilometer disposal site were located in the center of the site, the maximum elevation increase over a kilometer would be about 8 m (26 ft).

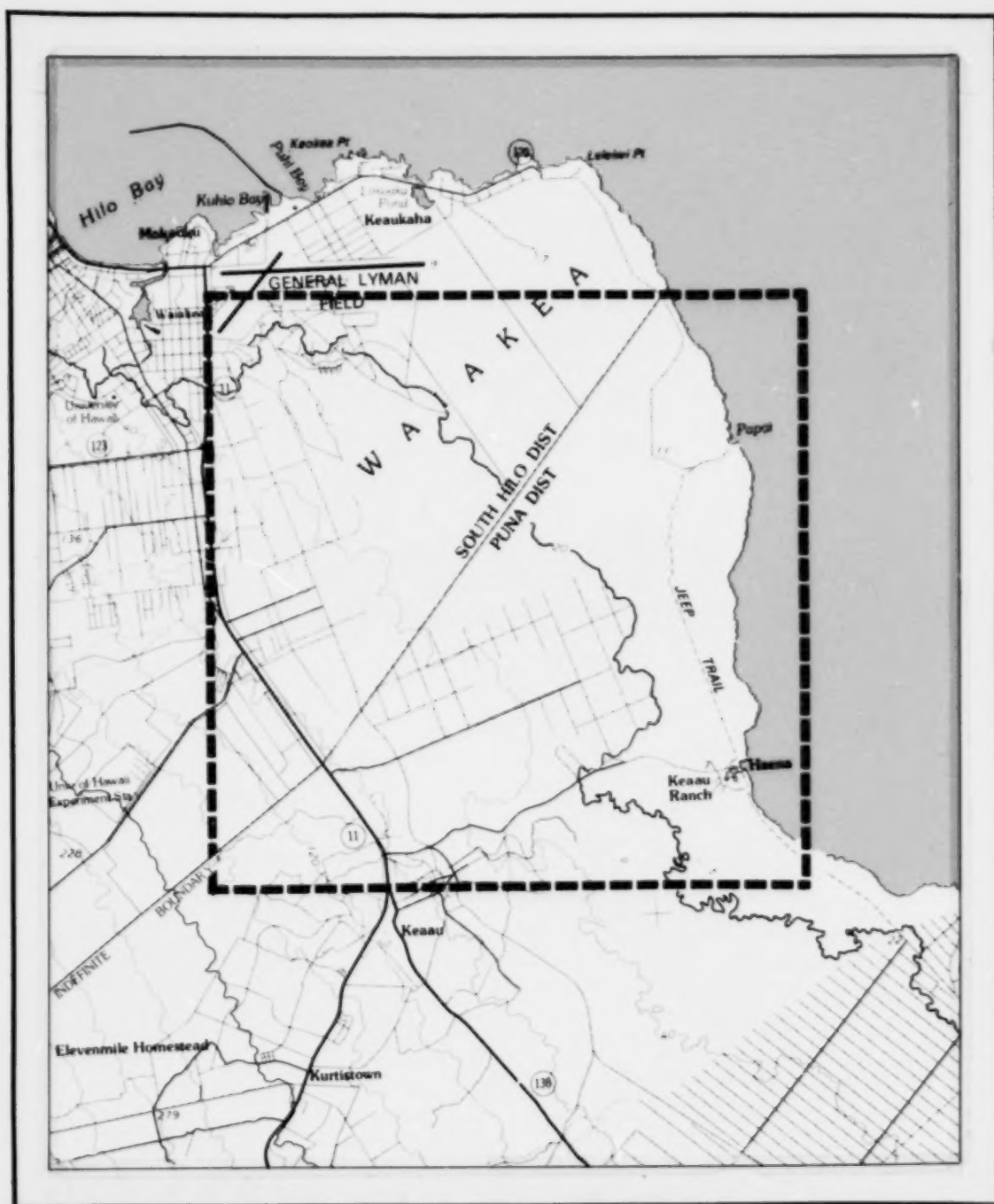
The Big Island is wholly volcanic and the site is formed on prehistoric Mauna Loa lava with little ash cover.

Volcanic eruptions are a potential geologic hazard in this area. Mauna Loa and Kilauea, the two youngest volcanoes on the island, are both active. Mauna Loa erupted in 1975, and Kilauea erupted in 1979. Kilauea is located on the southeast flank of Mauna Loa. Most eruptions occur at the summit or in rift zones, areas where fissures penetrate the mountain. Kilauea's summit and caldera are closer to the site (about 37 km [23 miles]) to the center of the site than are Mauna Loa's; Mauna Loa's northeast rift zone extends toward Hilo and the site. The closest recorded lava flow to the site, about 8 km (5 miles) from the site's center, is an 1881 flow that originated from Mauna Loa's northeast rift zone. It has been determined that any eruption in Mauna Loa's northeast rift zone below an elevation of about 3,500 m (11,500 feet) would flow toward Hilo. Kilauea's eastern rift zone produced a lava flow in 1840 that is about 19 km (12 miles) from the site's center. However, flows from this rift zone should flow south of the site.

Volcanic hazards are ranked by assigning relative risk values to different areas. The zones range from A to F, with the F zone being the most hazardous. The Hilo site is within the eastern portion of an E zone, although even within this zone there is a fair amount of difference in degree of hazard. The site, relative to other locations within E zones, is distant from active rifts.

Other possible hazards include earthquakes and tsunamis. Since 1929 eight earthquakes with a Richter magnitude of 6 or greater have occurred on the Big Island. The strongest earthquake occurred in 1868 with an approximate magnitude of 7.5. A 1975 earthquake registered 7.2 on the Richter scale. Damage caused by shaking is not confined to specific areas and the whole island is susceptible to the hazards of earthquakes. In recent years the earthquakes have tended to occur on or near Kilauea. The risk of structural damage increases in areas of steep or unstable slopes and other potentially unstable lands. The site, therefore, is susceptible to the effects of earthquakes, although there are no steep slopes. Tsunami inundation can cause serious damage to coastal areas, but there is no hazard to the Hilo site because it is outside of the inundation zone.

The soils of the site support fairly rich vegetation consisting mostly of guava, ferns, tree ferns, Hilo and baret grasses, Kukui, ohia trees, and hala, while the exposed pahoehoe lava, which is much less densely vegetated, supports lichens, mosses, and scattered vegetation consisting mostly of ferns.



0 km 1 2 3 4 5 6 7 8 9 10
0 miles 1 2 3 4 5 6

CONTOUR INTERVAL 40 METERS
SUPPLEMENTARY CONTOUR INTERVAL 20 METERS



FIGURE 17. - The representative site for the Hawaii wet climate siting region near Hilo, Hawaii County.



FIGURE 18. - Representative terrain of the Hawaii wet climate siting region.

The climate of the Big Island is dictated by the northeast trade winds, which, in turn, are governed by a semi-permanent high pressure cell to the northeast of Hawaii. The trade winds travel 3,000 miles over the Pacific before encountering the islands. The moisture condenses as the winds move up the mountains thereby depositing rain on the windward side of the mountains. The orographic rainfall increases sharply with elevation to 600-1,200 m (2,000-4,000 feet) where peak rainfalls occur as the winds begin to flow around, rather than up, the mountains. The Hilo site receives an average range of 330-451 cm (130-180 inches) of rain a year. The area receives rain an average of 300 days a year with December and March being the wettest months and June the driest. Heavy rains can occur within short periods, but thunderstorms are infrequent. Rain accumulations of over 25 cm (10 inches) in a 24-hour period are not uncommon for the Hilo area. The heaviest recorded rainfall in a 24-hour period was an accumulation of 49 cm (19.2 inches) on March 1922.

Pan evaporation rates have been recorded at the Hilo Airport. The average evaporation rate is 12 cm (4.7 inches) per month. The lowest evaporation rate is 8.1 cm (3.2 inches) for the month of January and the highest rate is 19 cm (7.5 inches) for the month of August. The average is about 142 cm (56 inches) per year. The pan evaporation rate decreases across the site as the elevation increases. Precipitation substantially exceeds Class A pan evaporation in every month (see appendix B).

The trade winds are more constant during the summer than the winter; their presence ranges from a maximum of 90% of the time in July to a minimum of 50% in January. During the day, the site receives an average wind speed of about 15 mi/hr from the east, which is relatively constant when the trade winds are present. At night, the prevailing wind blows from the southwest off the slopes of Mauna Loa. The area's

strongest winds are not associated with the trade wind; they accompany winter storms, thunderstorms, and infrequent hurricanes. The skies over the Hilo area are cloudy (eight-tenths or more sky cover) 58% of the time and they are clear (three-tenths or less sky cover) 8% of the time.

Air quality in the Hilo area is good. TSP concentrations average $34 \mu\text{g}/\text{cu m}$, and sulfur dioxide concentrations are less than $5 \mu\text{g}/\text{cu m}$. (Hawaii State regulations require concentrations less than 55 and $20 \mu\text{g}/\text{cu m}$, respectively.)

For water resource planning purposes, the site is located within the second of five hydrographic areas for the island. Within Hydrographic Area II it is estimated that 24% of the rainfall is lost to evapotranspiration, 34% occurs as runoff, and 42% becomes groundwater recharge. However, relative to other areas within this hydrographic unit, it would be expected that, for the site, runoff would be lower and groundwater recharge would be higher.

Despite the large amount of rain, there are no perennial streams on the site, nor are there any floodprone areas. Watersheds and drainage basins are nonexistent. Rain rapidly infiltrates through the thin soil and the basaltic lava beneath it to become part of the groundwater. Throughout the site there is hydraulic continuity from the surface of the ground to the groundwater. The site's groundwater is part of a large basal water lens floating on salt water, known as the Ghyben-Herzberg Lens. Water that is not evaporated or taken up by vegetation flows laterally through the basalt at the water table and escapes at sea level as diffuse flow along the coast. The coast of the Hilo area is one of the greatest basal groundwater catchment areas. The groundwater exudes at a fairly constant rate and it is one of the main terrestrial influences on near coastal waters. For example, the average flow to Puhi Bay, which is north of the airport, is about 100 million gal/day. The coastal areas are susceptible to nonpoint pollution because of the heavy rainfall, the character of the soils and basalt subsurface, and the groundwater flow. This is a problem with leachate from cesspools in urbanized, nonsewered areas of Hilo.

The zone of transition, where the salt water and fresh water come into contact is dependent on the fluctuation of the tides, the amount of recharge, and any discharges by pumping. The mixing of fresh water and salt water is the greatest near the shore where tidal fluctuations have a greater effect. This mixing in the zone of transition is the only significant source of groundwater salinity.

Drilled wells on or near the site indicate the characteristics of the groundwater. A well at the Hilo Airport, just north of the site, encounters a static water level at a depth of 5 feet with pumped water having a chloride content of 108 ppm. A well at about the midline of the site but just west of the site's western boundary records a static water level of 4 m (13.1 ft) deep with a chloride count of 8 ppm. This well is a part of the Hilo water supply system; its pumping rate is 2,200 gal/min with a drawdown of 1.6 feet. A well near the site's southern boundary encounters water at a depth of 8.5 feet with 60 ppm of chloride. These three wells are listed as being in use supplying water for domestic use (155). An abandoned well in the site's northeast corner found water at a depth of 1 m (3.4 feet) with 688 ppm chloride. Two wells just south of the airport and adjacent to the National Guard Armory are not in use because the water is not potable. Two springs just north of the site flow toward the ocean, away from the site, but no records are available for them. Analysis of well data indicates an average water table gradient of about .9 m/km (5 ft/mi) from the coast. Contour lines indicating the chloride content of groundwater based on well data were prepared by the U.S. Geological Survey (83). The map shows that higher chloride content contours radiate further inland from

the northeast corner of the site. Chloride content decreases more rapidly from the coastal areas near the northwest and southeast corners of site; 250 ppm was found less than a mile from the coast at these corners, but it is about 2 miles from the coast at the northeast corner. These areas would not be suitable for groundwater production for domestic use since 250 ppm is the usual limit placed on chloride concentration for domestic use.

Sociocultural Characteristic

Hilo is the largest city on the Big Island and the second largest city in the state of Hawaii. With a 1980 population of 34,700, it is the principal urban, business, and commercial center on the island. Yet most of the area of the Hilo site is undisturbed by development, even though it is adjacent to the city. The northern boundary of the site is less than two miles from the port. The site is divided almost equally between the South Hilo and Puna districts.

Roughly 70% of the land on the Hilo site is either undeveloped range land or forest land, and nearly 25% of the land is used for agricultural purposes. The largest agricultural tract, which consists of macadamia orchards, is located in the central part of the Puna portion of the site. Other agricultural uses, which are scattered on smaller plots of land, are flower and horticulture production. Virtually all of the small amount of built-up or disturbed land occurs in the northwest corner of the site. Most of this land is either active or abandoned quarries. The extreme northwest corner of the site is used for industrial purposes. Hilo's solid waste disposal dump and a State National Guard armory are also located in the northwest corner. A residential area is found at the midpoint on the western boundary.

In 1961, Hawaii adopted a general plan and a land use law, which called for the designation of all lands into four land use districts: urban, rural, agricultural, and conservation. Almost all of the site is classified agricultural with the exception of a small portion, which is urban, in the northwest corner of the site. The State establishes regulations for the use of land in the agricultural district, but it is the county's responsibility to administer those regulations. In general, the State requirements are minimal and are subject to county land use controls.

Most of the land on the site is owned by the State of Hawaii. This land is located in the central portion of the northern half of the site in the South Hilo district. The only significant private land holdings are in the Puna district portion of the site. A segment of land in the central portion of the eastern boundary is owned by the Hawaiian Paradise Park Corp. This area is zoned for resort and alternate urban expansion. The remaining land in the Puna district portion of the site is owned by W. H. Shipman, Ltd. and is used for macadamia orchards. A band of land along the site's western boundary and in the northeast corner is designated Hawaiian Homes Land.

The County of Hawaii's land use allocation map places most of the site's land in the category of orchards. Macadamia nuts and papayas could be supported in this area. The lands immediately south of the airport and in the site's southwest corner are designated as industrial. A small amount of land along the northern portion of the western boundary of the site is allocated as low density residential and alternate urban expansion. The northeast corner of site in the Puna district is designated as resort encircled with alternate urban expansion, presumably to accommodate possible resort development in the future.

The county's zoning districts and the zoning guide map for the Hilo Community Development Plan (17) generally agree with the county's land use allocation map. Most of the land is zoned agricultural and an industrial zoning district is in the northeast corner of the site.

Hawaiian Homes Land is being developed for residential uses along the central portion of the western boundary, just east of Route 11. The State Department of Hawaiian Homes Land administers this land, which is reserved for use by the descendants of the native Hawaiian population. These lands must be used in accordance with the land uses designated in its charter. Land not in these uses are subject to the county's zoning regulations. Hawaiian Homes Land cannot be sold, but it can be used in exchange for other land with the State Department of Land and Natural Resources (DLNR).

The Hilo Community Development Plan identifies the area south of the airport, within the site boundary, as having the greatest expansion potential for industrial development. The plan recommends this area as the future major industrial area of Hilo and the Big Island. In accordance with the industrial development of the area, the plan also recommends extending Puainako Street into this area and constructing an energy-materials transit corridor connecting the industrial area and the harbor. The corridor would be located either west of or under the western part of the airport runway. It could transport fuels, raw materials, and products as well as connect a sewer line from the site to the sewage treatment plant. The Plan suggests that the National Guard armory be relocated.

Although it was published in 1975, the Hilo Community Development Plan recognizes the interest in developing the manganese nodule industry in the Hilo area. The plan suggests exploring the possibility of establishing a duty-free zone or Foreign Trade Zone for the industry. The zone would be located adjacent to the Energy Trade Material Corridor, behind the airport, and it would allow the metal products destined for foreign countries to be processed outside of U.S. trade regulations. The plan also recommends that the harbor depth be dredged from its present depth of 10.6 m (35 feet) to 12 m (40 feet), that an additional pier be constructed, and that the airport runway be lengthened and its facilities improved.

The existing public water supply system (335) does not operate wells in the site, although the two Panaewa wells are adjacent to the middle of the western boundary and have a combined capacity of 5 million gal/day. A third well is planned. The electric company operates wells in the northwestern portion of the site. The Olaa-Mt. View Water System consists of two domestic deep wells near Keaau, just south of the site. Three Puna Sugar Company wells, also near Keaau, produce about 11 million gal/day for sugar cane processing operations. No public water supply wells are proposed for the land within the site.

The most recent plans (1980) propose construction of a new sewage treatment plant in the northeast corner of the site, just west of the Hawaii National Guard. The treated sewage would flow to the existing sewage treatment plant and be deposited into the ocean at a depth of about 20-27 m (70-90 feet). No sewer lines are currently within the site.

All of the land on the island, with the exception of the forest reserve area, are within Hawaii's Coastal Zone Management Program Administrative Area. This is most of the land on the island, including the site area. However, only the coastal area up to about a mile inland, which includes the eastern part of the site, is within the Special Management Area.

One other proposed plan that affects the site is the Lava Flow Control Plan prepared by the COE. This Plan presents various alternative methods for diverting possible future lava flow from Mauna Loa's northeast rift zone away from the developed part of the city of Hilo. Two of the five alternatives would divert lava through the center of the site roughly along the South Hilo-Puna district boundaries to the eastern coastal area of the site.

Geothermal energy may be an additional attraction of the site. Geothermal energy wells are being tested near Cape Kumukahi in the eastern rift zone of Kilauea, about 24 km (15 miles) from the site's center. The HGP-A well is the world's hottest well, and there are indications that there is a significant reservoir that could be exploited profitably. At this time many questions remain unanswered about the feasibility of geothermal energy; however, they may be resolved by the time industry is ready to begin planning for mining operations.

There are no areas designated as special environmental or cultural areas (8, 16, 17, 74, 97, 142, 144, 145, 159, 176, 217, 273, 408). No identified archaeological or historic sites, habitats of important flora or fauna, natural areas, animal sanctuaries or wetlands are located on the site. However, early Hawaiian populations may have settled in the Hilo area, and State regulations require that a survey for possible archaeological sites be submitted to DLNR before any development begins.

Kohala: Hawaii Dry Climate Representative Site

Biophysical Characteristics

The Kohala site (figure 19), located in the South Kohala district, is primarily a dry grassland at the base of the Kohala mountains and Mauna Kea (figure 20). The site can be viewed as being composed of three sections. The northern third of the site east of Route 270 lies at the base of the Kohala Mountains. Physiographically, it is referred to as the Walaka slightly dissected upland. The slope, which rises in a northeast direction from the coast, ranges from 10 to 12%. The highest elevation on the site--1,000 m (3,300 ft)--is within this section, in the northeast corner of the site. If a square kilometer disposal site were located within this section, the maximum elevation rise over a kilometer would be about 120 m (400 ft). This section of the site has ephemeral streams that have created mostly gullies and a few gulches in the mountain side. There are very few improvements in this area.

The second section is the southern two-thirds of the site east of Route 19 (where it follows the coast). It is divided from the northern section by Makeahua Gulch, which runs alongside Route 19 after it turns east from the coast, toward Waimea. The section is within the Waimea slightly dissected upland and its uniform slope is half that of the northern section--about 6%. The slope rises east, perpendicular from the coast, to reach a maximum elevation of about 500 m (1,650 ft). A square kilometer disposal site in this area would have an elevation rise of about 60 m (200 ft) over a kilometer. There are very few improvements; most of the land is used for cattle grazing. Of the three sections, this section appears to be the best suited for a mineral waste disposal site because of the gentler slopes and the lack of development.

The third section of the site is the coastal area between the shoreline and the two coastal roads: Routes 19 and 270. Physiographically, the area is within the Waimea slightly dissected upland with a small part in the south lying within the Kiholo lava plain. The principal reason for identifying this area as a separate section is that most of the development occurs here, including the port of Kawaihae, recreational beaches and parks, residential developments, and Puukohola Heiau, a national historic site.

Lava flows from the Kohala volcano are responsible for the geology in the northern section of the site, while lava from the Mauna Kea volcano has covered the southern two-thirds of the site. The thin soils, which are interspersed with patches of exposed lava, are well drained (see appendix B).

There is little risk from volcanic eruption throughout the site. The northern third is within an A volcanic hazard zone and the southern two thirds are within a B zone (A is the least hazardous zone). As mentioned earlier, any place on the island is susceptible to the shaking associated with earthquakes, even though in this case most of the earthquake epicenters are located on the other side of the island. Tsunami inundation is also a potential hazard; although all inundation areas are west of the coastal roads, Routes 19 and 270. The tsunami inundation area does not extend more than 600 m (2,000 feet) inland except for Kawaihae Harbor, where the man-made portion of the port extends into the water and there is a potential risk for most of the port facilities. Tsunami damage is less likely to occur on the west coast than on the east coast.

The weather of Kohala is usually dry, sunny, and calm. Typical of orographic rainfall, the leeward side of the mountains, where the site is located, receives little rain. The average rainfall for the site is about 25 cm/yr (10 in/yr) and part of the site is within



FIGURE 20. - Representative terrain of the Hawaii dry climate siting region.

the driest area on the island, which is the leeward side of the Kohala Mountains. Also because of the orographic rainfall pattern, the site receives most of its rain from winter storms from the south, not from the trade winds. The village of Puako, which is just west of the site, receives only 3% of its rain during the three summer months, while the month of January accounts for 18%. High rainfall in short periods is uncommon: Puako receives .25 cm (.1 inches) or more rain on an average of 13 days a year.

Few weather stations near the site record pan evaporation rates; however, the station with climate characteristics most similar to the site is Station 3 near Hawi, which is near the tip of the island's most northern peninsula. This station's mean annual evaporation rate is 245 cm (96.5 inches). As seen in figure B-12, summer evaporation rates exceed winter rates: July's mean rate is 25.2 cm (10 inches) and December's rate is 14.5 cm (5.7 inches).

Winds approach the Kohala site primarily from the west-northwest with the next dominant wind being from the opposite direction, the east-southeast. This reflects normal diurnal changes; the wind usually blows onshore from midmorning until sunset and offshore from early evening until the next morning. The average wind speed over the site is less than it is for most areas on the Big Island; they exceed 8 mi/hr only about 26% of time and very rarely do they exceed 20 mi/hr. As expected, cloud cover is uncommon.

Air quality is good. TSP average $29 \mu\text{g}/\text{cu m}$, carbon monoxide averages .15 ppm, sulfur dioxide averages .01 ppm, and nitrogen dioxide averages .02 ppm.

The site is within the fifth of five hydrographic regions for the island. For this hydrographic region it is estimated that, of total rainfall, 64% is returned to the air via evapotranspiration, 16% occurs as runoff, and 20% recharges the groundwater (148). However, this hydrographic region includes many areas that receive more rain and cloud cover than does the Kohala site.

There are no perennial streams within the site and most of the ephemeral streams are located in the site's northern section. These ephemeral streams have cut gullies and a few gulches in the leeward side of the Kohala Mountains. Very infrequent flash flooding has occurred, mostly along the developed, low coastal areas. High intensity storms have flooded the coastal highways, Hupuna Beach Park and Spencer Beach Park.

As is the case with the Hilo site, the groundwater in the Kohala site is basal water floating on ocean water in lava flows, that is, the Ghyben-Herzberg lens. However, fresh water does not seep to the ocean at the coast; rather, sea water exerts a greater influence on groundwater than vice versa. The zone of transition is close to the surface and brackish water may be found up to 4 km (2.5 miles) inland. Total ionic concentration (composed primarily of sodium, potassium, and chloride ions) for the site's wells is high, as compared to wells that are similar distances from the coast in other areas of the island. A maximum chloride concentration of 500 mg/l can be found at about 2.4 km (1.5 miles) inland throughout the site (83). The average static groundwater level for a well 4 km from the coast along Route 19, as it runs east, is 1.6 m (5.2 feet) and the chloride content is 254 ppm. Another well 1.6 km east of the first well records a static ground water level of 1 m (3.3 feet) with a chloride content of 302 ppm. Two wells along the coastal road south of Kawaihae have average chloride concentrations of 450 and 430 ppm, respectively, and depth to the water level is only a few feet. These wells are used either for irrigation or as a supplement that is mixed with water with lower salt concentrations. Potable water is drawn from wells directly east of Puako at an elevation of 365 m (1,200 feet), about 6 km (3.7 miles) from the coast (155).

Sociocultural Characteristics

The Kohala site has few improvements and is sparsely populated. Its population density is in the range of 1-4 persons per sq km. However, the population is increasing and is expected to continue to increase as developments expand north from the Kona coast. In 1970, South Kohala's population was 2,310 persons, of which about 750 were attributed to Waimea. The 1978 estimates for the district were 3,400 persons, about a 50% increase. This growth was mostly along the coastal areas and in Waimea village.

Most of the site's land is open range land, part of which is used for cattle grazing. Virtually all development within the site is along the coast, west of the coastal roads. This includes the Kawaihae port, a U.S. Coast Guard station, the Mauna Kea Beach Hotel, and scattered residential and commercial developments. Also included in this coastal area are two beach parks and a national historic site.

The 35-foot-deep Kawaihae port is the only other deepwater port on the island besides the port of Hilo. Storage facilities, a wood slicing plant, and service oriented industries are located around the port. Plans project increased use of this harbor.

Most of the site's land is owned by a few. The two major private landowners are the Parker Ranch and Queen's Hospital. The State of Hawaii owns a band of land about 2.4 km (1.5 miles) wide that runs diagonally from north-southwest to east-northeast across the southern section of the site. The northwest corner of the site is under the jurisdiction of the Hawaiian Homes. The coastal lands are under various private and

public ownerships. There are indications that the Parker Ranch may accommodate development pressures and sell some of its land east of coastal Route 19. Housing in South Kohala is almost exclusively single family and its housing supply in 1976, 1,609 units, was more than double its 1970 supply of 793 units.

In accordance with the State Land Use Commission's general plan, the coastal area of the site is classified as an urban district and the rest is within the agriculture land use district. The county of Hawaii's 1980 zoning map indicates that most of the land west of the coastal roads is zoned for extensive agricultural use (74). A small portion of the northwest corner is zoned for intensive agricultural use, and an open space zoning district is along the middle of the southern boundary. The coastal land west of the coastal roads is zoned for a number of uses, including low- and medium-density residential and open space south of Kawaihae. The area around the harbor is zoned industrial. The 1971 General Plan for the County of Hawaii stated that there were 195 acres of industrially zoned land around the Kawaihae harbor, but that 144 acres were vacant. A "bubble" zoned alternative urban expansion surrounds the intersections of Routes 19 and 270 and Kawaihae harbor.

The major source of water for the site is from treated stream water that flows toward the coast from the Waimea Treatment Plant. The pipeline follows Route 19 east. Two deepwater wells along the pipeline's route at 175-m (570-foot) elevation with salinity concentrations too high for domestic use supplement the treated water. Also serving the area are the two Lalamilo wells at about the 350-m (1,150-foot) elevation mark. The pipeline from Waimea follows Route 19 to its intersection with Route 270, where the pipeline splits. One pipeline follows 270 north to Kawaihae and the other follows 19 south to Puako. A pipeline from the Lalamilo wells flows almost due west toward Puako (335).

Total capacity for the area including the Waimea Treatment Plant water, the two supplemental wells and the Lalamilo wells is 6.05 million gal/day. Projected water demand estimates vary. The 1980 State Water Resource Development Plan projects a 1990 demand of 1.3 million gal/day while the Hawaii County Department of Water Supply expects increased growth to result in a 1990 demand of 5.1 million gal/day (335).

DLNR's Division of Land and Water Development has prepared a plan to substantially upgrade the Lalamilo water system. The system would result in four freshwater wells at 300-365 m (1,000-1,200 foot) elevation, three brackish mixing wells at about the 180-m (600-foot) elevation, storage tanks, and pipelines. The purpose of this plan is to provide the water needed to encourage large-scale resort development to the South Kohala coast. The plan states that further development is forestalled by a lack of sufficient water. As mentioned previously, developments for tourism are expected to increase as developments along the Kona coast expand northward.

There are no sewage treatment facilities within the site.

As is the case for Hilo, all of the site is within the CZM program administrative area, but only the coastal area of up to about a mile inland is within the Special Management Area. Archaeologic sites are probably the only areas of recognized special environmental or cultural importance, other than the beaches and parks already mentioned. Parts of the site, particularly coastal lands, were populated by Hawaiians before the island was visited by Europeans. DLNR requires an archaeological survey before construction can begin.

Results of the Environmental Assessment

In order to assemble the three previous discussions into an environmental assessment that highlights effects that are likely to be significant, we have prepared five environmental assessment matrices (tables 11-15). For various combinations of waste disposal technique (the columns of the matrix) and potential effect (the rows in the matrix), these tables indicate which classes of process are likely to contribute to that effect. Classes of process are coded in the table as follows, according to the type of reject they produce:

Three-metal hydrometallurgical process tails	3
Four-metal hydrometallurgical process tails	4
Slags	5

An entry of 3, 4, or 5 in the matrix indicates that there is potential for the effect occurring at a significant level for that class of process at the site. A 3, 4, or 5 indicates potential for an impact or major beneficial effect. A blank in the matrix indicates that the effect is unlikely to be significant for a particular site/process/disposal technique combination. The blanks include all combinations of waste disposal techniques and potential effects that were designated as no problem (NP) and not applicable (NAP) in table 10. Only effects that were thought to be affected significantly by at least one of the disposal techniques for one of the processes at the site are listed. The comprehensive list of effects that were considered in developing the matrices is found in the beginning of this chapter. The ratings applied are subjective and are meant to compare the relative importance of different effects at each site. Ratings apply to the better conditions available at the sites. No comparisons between sites based on the matrices were intended or should be made.

The following paragraphs briefly explain the table entries for each site.

Pacific Northwest Site (Cherry Point, Washington)

Because of the presence of important waterfowl areas, flyways, and environmental reserves on and near the site, attraction of wildlife could be a major problem at this site for impoundments. Aquifer contamination is a potential problem of less significance because of the limited yields of the aquifers. Conflicts with farmlands are possible but the site has already successfully incorporated a mix of industrial uses.

Retention structure failure is a potential effect both because because the site is located in a high seismic risk zone and because the geologic materials are prone to effects from earth shaking. This risk can be mitigated by design, and the limited watershed areas and absence of major downstream land uses reduce the chances of a major catastrophe. Large tailings dams have been constructed in British Columbia with similar geologic and seismic conditions (192). The terrain is flat enough to permit flexibility in designing containment structures. Marine habitat may be an issue because of the high value of Puget Sound to marine species and the tendency to locate industrial facilities near the coast.

Evaporation ponds would not be very effective because of climatic conditions, and therefore it is unlikely they would be used at this site. If the ponds were used, effects similar to retention structures would apply.

TABLE 11. - Environmental assessment matrix for the Pacific Northwest representative site

Potential effect	Class of waste disposal technique			
	Above-surface retention structures	Specially excavated pits ¹	Dewatered tailings and slag	Evaporation ponds ²
Aquifer contamination..	3,4	3,4		3,4
Retention structure failure.....	3,4			
Attraction of wildlife.....	<u>3,4</u>	3,4		<u>3,4</u>
Displacement of important farmlands..	3,4	3,4	3,4	3,4
Degradation of marine habitat.....	3,4	3,4		3,4

¹ Backfilling mines and deep disposal are not relevant at this site.

² Evaporation ponds are not likely at this site.

NOTE.--3, 4, and S indicate potential for a significant effect for three-metal tails, four-metal tails and slags respectively. 3, 4, and S indicate potential for a serious impact or a major beneficial effect for the corresponding classes of process.

Southern California Site (Casmalia)

Because of possible application of State hazardous waste regulations and the scarcity of potable water, the principal determinants of the acceptability of a site in Southern California for disposal of rejects other than slag will be the absence of usable groundwater or the presence of adequate natural geologic barriers over usable groundwater. These conditions will be difficult to establish. Although the potential for aquifer contamination exists for part of the site, the licensability of the Casmalia Class I disposal facility indicates that acceptable conditions can be expected to occur on parts of the site. Therefore, potential for a significant but not major impact is shown for aquifer contamination. Also because of the scarcity of water, water consumption may be an issue. Fugitive dust is a major problem because of existing substandard air quality and dry conditions. Retention structure failure could also be an issue since the areas that have more favorable geologic conditions for waste disposal have steeper slopes and a higher potential for landslides. Seismic events of a large magnitude have been experienced in the vicinity of the site. The rougher terrain required to use the more favorable geology on this site in conjunction with seismicity increase the probability of spills, although oil and gas pipelines are common near the site. Land reclamation is potentially a beneficial effect for surface mines.

TABLE 12. - Environmental assessment matrix for the Southern California representative site

Potential effect	Class of waste disposal technique			
	Above-surface retention structures	Specially excavated pits/backfill mines ¹	Dewatered tailings and slag	Evaporation ponds
Fugitive dust.....	<u>3,4</u>	<u>3,4</u>	<u>3,4</u>	
Aquifer contamination..	<u>3,4</u>	<u>3,4</u>		3,4
Retention structure failure.....	3,4			3,4
Water consumption.....	3,4	3,4		
Land reclamation.....		3,4, <u>S</u>	3,4, <u>S</u>	
Spills of rejects in transit.....	3,4	3,4		3,4

¹ Deep disposal is not relevant at this site.

NOTE.--3, 4, and S indicate potential for a significant effect for three-metal tails, four-metal tails and slags respectively. 3, 4, and S indicate potential for a serious impact or a major beneficial effect for the corresponding classes of process.

Gulf of Mexico Site (Corpus Christi, Texas)

Fugitive dust is a possible major effect at the Corpus Christi site because of dry conditions and high wind erosion potential. Land use conflicts with farmland and residential expansion are also possible. Recent resistance to proposed dredge spoil disposal sites indicates that public acceptance of the facility may be a problem. Aquifer contamination is possible but the presence of muds and clays with permeability reduces that likelihood, and an already high chloride content in groundwater at the site reduces the significance of this effect. Visual conflicts are possible because of the very flat agricultural (non-wooded) terrain. Because of the flat stream valleys and hurricane-related flooding, additional precautions against surface water contamination are required. Wildlife associated with coastal bays on the Gulf could be attracted to the site by large impoundments.

TABLE 13. - Environmental assessment matrix for the Gulf of Mexico representative site

Potential effect	Class of waste disposal technique			
	Above-surface retention structures	Specially excavated pits ¹	Dewatered tailings and slag	Evaporation ponds
Fugitive dust.....	<u>3,4</u>	<u>3,4</u>	<u>3,4</u>	
Surface water contamination.....	3,4			3,4
Aquifer contamination..	3,4	3,4		3,4
Water consumption.....	3,4	3,4		3,4
Attraction of wildlife.....	3,4	3,4		3,4
Conflicts with land use.....	<u>3,4</u>			3,4
Displacement of important farmlands..	<u>3,4</u>			3,4
Visual conflicts.....	<u>3,4</u>		3,4	3,4
Socioeconomic effects..	3,4		3,4	3,4

¹ Backfilling mines and deep disposal are not relevant at this site.

NOTE.--3, 4, and S indicate potential for a significant effect for three-metal tails, four-metal tails and slags respectively. 3, 4, and S indicate potential for a serious impact or a major beneficial effect for the corresponding classes of process.

Hawaii Wet Climate Site (Hilo)

The primary environmental concerns for the Hilo site are degradation of the groundwater and possible resultant effects on the near-shore marine habitat just north and east of the site. The soils and the pahoehoe and aa lava readily transmit water, and they may also cause support problems for a retention structure because of seepage below dams. Seismic activity is common enough to be a design consideration. Because of the extremely wet climate, evaporation ponds would not be effective. Also, extremely poor soils make land reclamation desirable.

TABLE 14. - Environmental assessment matrix for the Hawaii wet climate representative site

Potential effect	Class of waste disposal technique			
	Above-surface retention structures	Specially excavated pits/backfill mines ¹	Dewatered tailings and slag	Evaporation ponds ²
Aquifer contamination..	<u>3,4</u>	<u>3,4</u>	<u>3,4</u>	3,4
Retention structure failure.....	3,4		3,4	3,4
Land reclamation.....			3,4, <u>S</u>	
Displacement of important farmlands..	3,4			
Degradation of marine habitat.....	<u>3,4</u>	<u>3,4</u>	<u>3,4</u>	3,4

¹ Deep disposal is not relevant at this site.

² Evaporation ponds are unlikely because of the water balance.

NOTE.--3, 4, and S indicate potential for a significant effect for three-metal tails, four-metal tails and slags respectively. 3, 4, and S indicate potential for a serious impact or a major beneficial effect for the corresponding classes of process.

Hawaii Dry Climate Site (Kohala)

Groundwater contamination and the subsequent degradation of the marine habitat are also problems for the Kohala site, although not as serious as for the Hilo site. Brackish water can be found up to two miles inland within the site and irrigation wells near the coast pump this water. Mixing wells are also found at about two miles from the coast. The current capacity of the public water system could present water consumption problems, particularly if the "worst case" estimate for future water demand is realized. However, the capacity of the water system is expected to be increased, and estimates for future water demand vary significantly. The dry climate and the fairly constant breeze, which generally blows onshore during the day, create the potential for fugitive dust problems. Retention structure failure is also a potential problem because of available structural material and the possibility of earthquake shaking. Conflicts with land use and visual conflicts may result, particularly for above-grade containments, if expanded tourist development occurs. Archaeological sites have been found along the coast and some may be found further inland, although no surveys have been completed for the area.

TABLE 15. - Environmental assessment matrix for the Hawaii dry climate representative site

Potential effect	Class of waste disposal technique			
	Above-surface retention structures	Specially excavated pits ¹	Dewatered tailings and slag	Evaporation ponds
Fugitive dust.....	<u>3,4</u>	<u>3,4</u>	<u>3,4</u>	
Aquifer contamination..	<u>3,4</u>	<u>3,4</u>	<u>3,4</u>	3,4
Retention structure failure.....	3,4			3,4
Water consumption.....	3,4	3,4		
Land reclamation.....			<u>3,4,S</u>	
Conflicts with land use.....	3,4	3,4	3,4	3,4
Interference with historical/archaeological sites.....	3,4	3,4	3,4	3,4
Visual conflicts.....	3,4			3,4
Degradation of marine habitat.....	3,4	3,4	3,4	3,4

¹ Backfilling mines and deep disposal are not relevant at this site.

NOTE.--3, 4, and S indicate potential for a significant effect for three-metal tails, four-metal tails and slags respectively. 3, 4, and S indicate potential for a serious impact or a major beneficial effect for the corresponding classes of process.

REGULATORY REGIMES

Synopsis of Relevant Regulations

In May 1980 the law firm of Nossaman, Krueger and Marsh published a study (304), written under contract with NOAA, summarizing the Federal and State laws and regulations that pertain to siting, construction, and operation of manganese nodule processing and related facilities. The study deals with the four West Coast states of California, Oregon, Washington, and Alaska. A comparable study (33) for the Gulf Coast states, conducted by Boston Technologies, Inc., has been completed in 1981. For the State of Hawaii, a report by NOAA and Hawaii DPED (176) deals in part with regulatory procedures.

These three reports provide the basis for the legal and regulatory review that follows. However, several new developments have occurred since publication of the Nossaman, Krueger and Marsh study. For example, EPA regulations covering underground injection control (UIC) have been published, as well as effluent guidelines and standards for primary copper smelting, including new source performance standards. There also have been several changes and additions to the RCRA regulations.

A major programmatic change that has far-reaching effects is the passage of the Consolidated Permit Program Regulations (CPPR), which cover five permit programs: (1) the Hazardous Waste Management Program under Subtitle C of the Solid Waste Disposal Act, as amended by RCRA; (2) the UIC Program under Part C of the Safe Drinking Water Act (SDWA), as amended; (3) the National Pollutant Discharge Elimination System (NPDES) Program under sections 318, 402, and 405(a) of the Clean Water Act, as amended; (4) the Dredge or Fill (404) Program under section 404 of CWA; and (5) the PSD Program under regulations implementing section 165 of the Clean Air Act (CAA), as amended. The CPPR cover basic permitting requirements for RCRA, UIC, and NPDES programs, as well as what a State must do to obtain approval to operate its own program in lieu of a Federal program, minimum requirements for administering its own program, and procedures for EPA processing of permit applications and appeals. For the Dredge or Fill Program, the CPPR apply to requirements for a State to administer its own program in State-regulated waters in lieu of the COE and to provisions for EPA veto of State-issued 404 permits. The CPPR also pertain to EPA processing procedures for PSD permits.

Section 8002 of RCRA instructed EPA to carry out a study of mining waste to determine adverse effects on the environment and to assess the adequacy of mining industry and government agency means of disposing of and utilizing such waste. The October 1980 amendments to RCRA added a new mining study of the adverse effects of "materials generated from the extraction, beneficiation, and processing of ores and minerals, including phosphate rock and overburden from uranium mining," to be conducted in conjunction with the aforementioned study. Two preliminary draft reports (320, 438) were completed in February 1981 in response to this mandate.

An amendment to RCRA was added on November 19, 1980, excluding from the hazardous waste regulations "solid waste from the extraction, beneficiation and processing of ores and minerals." Under this amendment, new facilities will not have to apply for or obtain a hazardous waste permit before construction or operation. However, EPA has expressed its intention to review the legislative history of this amendment and consider public comments in order to decide whether or not to narrow the exclusion in a subsequent rulemaking action.

Federal Regulations

The following Federal statutes and their concomitant regulations are relevant to manganese nodule waste disposal for all sites:

- o the National Environmental Policy Act of 1969;
- o the Federal Water Pollution Control Act (FWPCA), as amended by the Clean Water Act of 1977;
- o the Safe Drinking Water Act of 1974;
- o the Resource Conservation and Recovery Act of 1976;
- o the Clean Air Act Amendments of 1970 and 1977;

The following additional statutes, designed to protect resources that may or may not be involved at a particular site, may apply. Their applicability must be determined for each site.

- o the Coastal Zone Management Act (CZMA) of 1972;
- o the Fish and Wildlife Coordination Act (FWCA) of 1958;
- o the Endangered Species Act of 1973;
- o the National Migratory Bird Treaty Act of 1918;
- o the National Historic Preservation Act of 1966 and the Preservation of Historical and Archaeological Data Act of 1974;
- o the Wilderness Act of 1964; and
- o the Wild and Scenic Rivers Act (WSRA) of 1968.

Most of the regulations above are "as amended." The regulations that apply to manganese nodule waste disposal at all sites are discussed below. Discussion of the additional regulations that may apply is included in appendix C.

Where regulations specifically apply to waste disposal, their applicability to a manganese nodule reject facility may be discussed in the following subsections; otherwise, the discussion will be general.

National Environmental Policy Act of 1969

It is likely that the requirements of NEPA will apply to the construction and operation of manganese nodule processing and related facilities. Under NEPA, Federal agencies are required to:

"include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement...on (i) the environmental impact of the proposed action; (ii) any adverse environmental effects which cannot be avoided; (iii) alternatives to the proposed action; (iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity; and (v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action."

DSHRMA requires NOAA to prepare a site-specific EIS on a permit for commercial recovery. The preparation of this EIS by the responsible Federal agency must include consultation with and solicitation of comments from other Federal agencies having jurisdiction over the given subject area.

The process of preparing an EIS is governed by regulations promulgated by the Council on Environmental Quality (CEQ) in November 1978. These regulations provide guidance in ascertaining whether or not an EIS must be prepared for a given action. The main objective of the CEQ final regulations is to streamline and standardize the environmental process for all Federal agencies in implementing NEPA. Each agency is to prepare procedures for implementing these regulations. The agencies involved in manganese nodule reject disposal operations, including BuMines, NOAA, FWS, and EPA, have issued final procedures for implementing NEPA. Further changes to the NEPA process are currently under consideration.

Some Federal statutes governing Federal permit authority specifically circumscribe the application of NEPA. For example, FWPCA exempts EPA actions from an EIS requirement except in the case of issuance of permits to "new sources."

If a proposed agency action is not categorically excluded from EIS procedures, the agency may (1) prepare a document called an environmental assessment, which will identify key environmental considerations and aid the decisionmaker in determining whether an EIS is required, or (2) in certain clear-cut cases, begin preparation of an EIS without first preparing an environmental assessment. If an environmental assessment is prepared and a determination is made that the proposed action will not have significant effects on the environment, a finding of no significant impact must be prepared, setting out the reasons for not preparing an EIS. If preparation of an environmental assessment leads to a decision that an EIS is required, the formal EIS process begins. Notice is published in the Federal Register to solicit input for the agency's planning process. The next step is "scoping," a procedure that involves agencies and people with different viewpoints meeting to identify significant issues related to the proposed action. Based on standardized CEQ guidelines, a draft EIS explaining the proposed action and its environmental consequences is prepared. Following a 60-day review period, during which comments are solicited, the final EIS is prepared, reflecting the agency decision to implement one of the alternatives. The final EIS is filed with EPA and can be implemented after a period of 30 days.

An important point in the CEQ regulations is that the agencies are held responsible for mitigation and are encouraged to provide for monitoring. Permit issuance must be contingent on completion of prescribed mitigation measures.

Three executive orders that are based on the objectives set forth in NEPA apply to siting of a major waste disposal facility.

Executive Order 11514, Protection and Enhancement of Environmental Quality, sets forth responsibilities of government agencies and of CEQ under NEPA. CEQ is directed to evaluate Federal government policies regarding environmental effects and make policy recommendations to the President and the agencies in order to protect the environment and resolve significant environmental issues.

Executive Order 11988 deals with floodplain management in furtherance of NEPA, the National Flood Insurance Act of 1968, and the Flood Disaster Prevention Act of 1973. The objective of this order is "to avoid to the extent possible long- and short-term adverse impacts associated with the occupancy and modification of floodplains and to avoid direct or indirect support of floodplain development wherever there is a practicable alternative." Agencies proposing to conduct, support, or allow an action to be located in a floodplain must consider alternatives to avoid adverse effects, and must incorporate the Unified National Program for Floodplain Management of the Water Resources Council into their regulations and procedures. Each agency is directed to

"provide leadership and...take action to reduce the risk of flood loss, to minimize the impact of floods on human safety, health and welfare, and to restore and preserve the natural and beneficial values served by floodplains in carrying out its responsibilities."

Executive Order 11990, Protection of Wetlands, is basically comparable to Executive Order 11988; however, the order "does not apply to the issuance by Federal agencies of permits, licenses, or allocations to private parties for activities involving wetlands on non-Federal property."

Federal Water Pollution Control Act as Amended by the Clean Water Act of 1977

FWPCA regulates both point source and nonpoint source pollution.

Point source pollution is regulated by EPA or by EPA-approved State programs under NPDES, by which pollutant discharges from point sources must have a permit and operate under certain imposed conditions. The principal substantive requirement under NPDES is the promulgation by EPA of effluent limitations. These limitations take two forms: technology based and water-quality based.

The minimum requirement for technology-based effluent limitations is the application of the "best practicable control technology currently available" (BPT). By July 1, 1984, however, existing discharges will be required to use the "best conventional pollutant control technology" (BCT) for conventional pollutants and the "best available technology economically achievable" (BAT) for toxic pollutants by that date or 3 years after the incorporation of applicable effluent limitations into the NPDES permit. The BAT must also be used for pollutants that are neither toxic nor conventional no later than July 1, 1987. In addition, EPA can issue more stringent standards for pollutants if it feels that such measures are appropriate. For new sources of pollution EPA is required to set "new source performance standards" for 27 industrial categories specified in FWPCA. Fifteen other categories have been added, including primary copper smelting, which may be applicable to the smelting process for manganese nodules. These categories are published as EPA effluent guidelines and standards.

The water-quality-based effluent standards are meant to establish compliance with water quality standards set by the States based on the designated use of a particular body of water. However, EPA is considering establishing national water quality standards.

EPA also has promulgated regulations on designation of hazardous substances under FWPCA and has determined reportable quantities of hazardous substances. A handler or discharger of these substances may be required to conform to best management practices (BMP). Except in certain cases (for example, compliance with a permit issued under RCRA or with an NPDES permit), those who discharge reportable quantities of these substances must notify the Coast Guard and face a civil penalty. If they fail to report such a discharge they are subject to criminal penalties.

For new sources, EPA may decide that an EIS is required. If this is the case, no construction can begin until the issuance of a permit incorporating the EIS requirements, including requirements not related to water pollution control. However, the preparation of an EIS may be waived by entering into a binding agreement with EPA incorporating necessary requirements or where EPA determines that there would be no significant impact if construction is begun.

Under CPPR, specified industries are required to supply quantitative data for outfalls containing toxic pollutants listed by EPA. Primary copper smelting is included under nonferrous metals manufacturing.

If the facility will be discharging into a municipal treatment system, it may have to comply with certain EPA pretreatment standards for pollutants rather than requiring an NPDES permit.

Federal nonpoint source pollution regulatory programs implementing nonpoint source pollution control requirements are in the early planning stages. One mechanism for identifying and controlling both point and nonpoint sources of pollution is the areawide waste treatment management plan. Using Federal funds, local groups or State agencies throughout the country are developing and publishing these plans, which include identifying mine-related sources of pollution.

The use of BMP, a secondary control mechanism, is becoming an important substantive requirement that may be applied in addition to or in the absence of other applicable standards. BMP would apply to both point and nonpoint pollution sources.

Safe Drinking Water Act of 1974

SDWA establishes two distinct regulatory programs. One develops and implements national drinking water regulations (both primary and secondary) governing public water supply systems, while the other regulates underground fluid injection activities.

EPA establishes national drinking water quality standards and establishes sampling and analytical reporting requirements. The program is administered by EPA or States with an EPA-approved program. None of the States in which the representative sites are located have EPA-approved programs.

The UIC Program sets requirements for State UIC programs to prevent contamination of drinking water sources. The Program includes constructing, operating, monitoring, and reporting requirements for four out of the five EPA-designated classes of wells (none developed yet for Class IV wells).

Two well classes, I and V, may apply to underground injection of decant water at manganese nodule reject disposal sites. Class I wells are "wells used by generators of hazardous wastes or owners or operators of hazardous waste management facilities to inject hazardous waste, other than Class IV wells," or "other industrial and municipal disposal wells which inject fluids beneath the lowermost formation containing, within one quarter mile of the well bore, an underground source of drinking water." Class II wells inject fluids associated with oil and gas development. Class III wells inject fluids for the extraction of minerals or energy. Class IV wells are used for disposal of radioactive wastes. Class V wells are wells that are not included in Classes I, II, III, or IV. The criteria and standards for Class I well construction have to do with casing and cementing requirements, requirements for appropriate logs and other tests to be carried out during well drilling, and standards for tubing, packer, and fluid seals. Class V well criteria and standards deal with submitting inventory information to EPA and assessing contamination potential and available corrective alternatives. Under the CPPR, Subpart C, certain aquifers may be designated "exempted aquifers" if they are determined to have no potential to be used as drinking water sources.

None of the States containing representative sites have received authorization to administer the Federal UIC Program.

Resource Conservation and Recovery Act of 1976

RCRA, as amended, sets forth requirements for the establishment of two types of solid waste treatment, storage, and disposal programs--one to be a Federally developed program for hazardous wastes and the other to be a State-developed program in accordance with Federal regulations for nonhazardous wastes. RCRA completely revised the Solid Waste Disposal Act.

EPA has issued guidelines for State solid waste management plans to assist states in preparing their plans. Included in these guidelines is a provision for coordination with other Federal programs, solid waste management plans of neighboring states, and plans for Indian reservations in the state. EPA also has issued regulations on criteria for classification of solid waste disposal facilities and practices. These criteria deal with floodplains, endangered species, surface water, groundwater, application to land used for the production of food-chain crops, disease, air, and safety.

Nonhazardous Solid Waste Management

If the manganese nodule rejects are determined to be nonhazardous or if the November 1980 exclusion of mining wastes remains in force and is interpreted to include rejects from ocean mining, the hazardous waste regulations would not be applicable, but the general guidelines for State solid waste management plans and the criteria for classification of solid waste disposal facilities and practices would apply. Under the guidelines no new open dumps will be permitted. Existing open dumps are to be either upgraded or closed. The State permitting system should provide for use or disposal of all wastes in an environmentally sound manner, by means of requirements for location, design, construction, operation, monitoring, reporting, completion, and maintenance of the facility. The State plan is required to develop a policy and strategy for encouraging resource recovery and conservation. The guidelines set forth requirements and recommendations for facility planning and implementation, coordination with other programs, and public participation.

Hazardous Waste Management

EPA is currently developing a comprehensive set of regulations for the disposal of hazardous wastes by landfilling and expects to promulgate these regulations in the near future. Under RCRA, EPA has developed criteria for identifying and listing hazardous wastes. Per these criteria a waste is considered hazardous if it has certain ignitable, corrosive, reactive, or toxic characteristics. The determination of toxicity is made by means of a test called the Extraction Procedure (EP), outlined in Appendix II of the EPA Regulations for Identifying Hazardous Waste (40 CFR 261). If the waste contains any of the contaminants listed in Table I, Subpart C, of these regulations in concentrations equal to or greater than those listed in the table, the waste exhibits the characteristic of EP toxicity, and is considered hazardous. Relevant parts of this table are presented as table 16.

EPA also has promulgated regulations for hazardous waste generators, for hazardous waste transporters, and for owners and operators of permitted hazardous waste facilities. In the case of manganese nodule rejects, should they be classified as hazardous, the processor would be the generator and the EPA regulations for hazardous waste generators would apply. The EPA regulations for hazardous waste transporters--manifesting and record keeping--"do not apply to on-site transportation of hazardous waste by generators or by owners or operators of permitted hazardous waste management facilities." The EPA regulations for owners and operators of permitted hazardous

TABLE 16. - Maximum concentration of selected contaminants
for the characteristic of EP toxicity

<u>Contaminant</u>	<u>Maximum concentration, mg/l</u>
Arsenic.....	5.0
Barium.....	100.0
Cadmium.....	1.0
Chromium.....	5.0
Lead.....	5.0
Mercury.....	0.2
Selenium.....	1.0
Silver.....	5.0

waste facilities deal with, among other things, location standards, surface impoundments (interim final regulations), and waste piles (interim final regulations).

The regulations regarding location require that a new hazardous waste treatment, storage, or disposal facility be at least 61 m (200 feet) from "a fault which has had displacement in Holocene times." These regulations also state that "a facility located in a 100-year floodplain must be designed, constructed, operated, and maintained to prevent washout of any hazardous waste by a 100-year flood unless the owner or operator can demonstrate to the Regional Administrator that procedures are in effect which will cause the waste to be removed safely, before floodwaters can reach the facility, to a location where the wastes will not be vulnerable to floodwaters."

The requirements for surface impoundments were written to apply to temporary storage and treatment of wastes. However, until EPA supplements these regulations to include other types of surface impoundments, including those not designed and operated to prevent discharge and those that are closed with wastes left in place, all permitted surface impoundments must comply with these regulations. The impoundment must have at least a 2 foot freeboard; must not discharge into the land, groundwater, or surface water (except NPDES-authorized discharges); and must be equipped with a leachate detection, collection, and removal system that meets certain criteria, and an impermeable liner. The earthen dikes must be free of burrowing mammals or perennial vegetation with roots that could jeopardize the structural integrity of the dike and create leaks, and must have a protective cover to minimize wind and water erosion and preserve the structure and integrity of the dike. An inspection and testing program and contingency plan must be followed to ensure proper operation of the facility.

Similarly, the regulations governing waste piles were intended to apply to temporary storage and treatment, but until EPA issues regulations governing other types of waste piles, these regulations will apply to all waste piles. Waste piles must be protected from wind and water erosion, and must be designed with a containment system that prevents discharge into the land, groundwater, or surface water. Run-on must be diverted from waste piles, and leachate runoff must be collected and

controlled. An inspection and testing program and contingency plan must be followed to ensure proper operation of the facility.

While a hazardous waste facility's permit application is pending, it may continue operating under EPA's interim status standards. EPA also has issued consolidated regulations on State permit programs so that States with approved programs can take over the administrative functions. While two of the States in which the representative sites are located (Washington and Hawaii) have not yet received EPA approval for Phase I authorization to enforce the interim status standards for existing facilities, California and Texas have received Phase I approval, and Texas has applied for Phase II approval to conduct the permitting program for existing and new facilities.

Clean Air Act Amendments of 1970 and 1977

Congress passed CAA in order to protect public health and welfare from adverse effects of air pollution. The 1970 amendments to CAA regulate the amount and type of air pollutants that a given facility at a given location can emit. EPA must set primary (public health) and secondary (public welfare) NAAQS of allowable concentrations of specific air pollutants. Under the 1977 amendments the States have primary responsibility for maintaining and enforcing air quality standards by means of State implementation plans (SIP's), which must meet with EPA approval. Under the SIP's, air quality control regions are designated as either attainment or non-attainment for particular pollutants.

In the case of a manganese nodule reject disposal site, the pollutant of concern is TSP derived from wind erosion and wind transport of fugitive dusts. The primary NAAQS for particulate matter are

- (a) 75 micrograms per cubic meter ($\mu\text{g}/\text{cu m}$)--annual geometric mean, and
- (b) 260 $\mu\text{g}/\text{cu m}$ --maximum 24-hour concentration not to be exceeded more than once per year.

The secondary NAAQS for particulate matter are

- (a) 60 $\mu\text{g}/\text{cu m}$ --annual geometric mean as a guide to be used in assessing implementation plans to achieve the 24-hour standard, and
- (b) 150 $\mu\text{g}/\text{cu m}$ --maximum 24-hour concentration not to be exceeded more than once per year.

In a non-attainment area, where air pollution levels for a particular pollutant exceed NAAQS, a new source may be allowed if the pollutant can be "offset" by reducing some other source of pollution in the area. In attainment areas, where pollution levels are below NAAQS, the new source may or may not be permitted. This depends on the regulations dealing with "prevention of significant deterioration." PSD areas are areas where the air is relatively clean. There are three classes of PSD areas. Class I areas, in which no major additional pollution (in this case TSP) sources are permitted, include all national parks and wilderness areas (mandatory Class I Federal areas) and may include additional areas named by the states. Federal land managers may identify "integral vistas," defined as views perceived from within the mandatory Class I Federal area of a specific landmark or panorama located outside the area. Criteria for identifying integral vistas must include the importance of the vista to the visitor's visual experience of the mandatory Class I Federal area. Integral vistas are to be listed in the SIP and a list is maintained by EPA. The SIP must set forth a strategy for remedying existing and preventing future impairment of visibility within mandatory

Class I Federal areas, including integral vistas. Class II and III areas can have some industrial development up to specified levels according to the SIP, with Class III allowing greater levels of pollutants from additional new sources.

In order to regulate fugitive dust emissions, an SIP may require the use of reasonable available technology in order to attain emission limitations. Examples of reasonable available technology include using water or chemicals on materials stockpiles, and oiling or paving of roadways.

State Regulations for the Representative Sites

In order to carry out the environmental assessment of the five representative sites, the State regulations that are likely to apply to manganese nodule reject disposal must be examined. Some Federal programs, such as NPDES permits, are administered at the State level in some states. Other programs administered at the State and local levels implement policies set forth in State statutes. Statutes and programs specifically dealing with waste disposal are summarized below for Washington, California, Texas, and Hawaii. Other statutes and programs that apply to a project of this nature are discussed in appendix C.

Washington

Waste Disposal

The major waste type to be disposed of from a manganese nodule processing plant will fall under solid waste regulations. However, liquid waste may be disposed of as well; for example, leachate and excess water collection systems will necessitate the disposal of liquid wastes. In Washington, liquid wastes are covered under the Federally authorized NPDES permit program administered by WDOE. Any discharge of wastes into the surface waters of the State requires an NPDES permit. Proposals that affect the quality of the State's waters require a Federal Water Quality Certification, also administered by WDOE. If waste is discharged into the State's groundwater or municipal sewer system, a State Waste Discharge Permit also is required. The regulations state that injection wells will not be authorized except under the most extraordinary circumstances. Pollution of ground and surface waters from these wells must be prevented. All of these permits are covered by the master application procedure under the Environmental Coordination Procedures Act (ECPA) of 1973.

The Solid Waste Management Recovery and Recycling Act (SWMRRA) of 1969, as amended, covers solid waste disposal. SWMRRA places primary responsibility for solid waste handling on county government. Following the minimum standards adopted by WDOE, each county, in cooperation with the cities, must submit a solid waste management plan to WDOE for review and approval. Regulations and permitting procedures for implementing the plan also must be developed by each county, city, or jurisdictional board of health. A separate permit system for disposal sites and facilities is established by SWMRRA. These permits are issued by the county health departments and must be renewed annually. SWMRRA further stipulates that an EIS is required with all new site applications. The county permits do not come under the master application procedure under ECPA.

The WDOE regulations for solid waste disposal set functional standards for location, design, construction, and operation of disposal facilities to avoid creating a nuisance and to comply with State and local land use, fire, and pollution prevention requirements, comprehensive plans, and standards. Surface water and groundwater

must be protected from pollution, and specific methods must be employed for leachate control in sanitary landfills. A 4-foot impervious soil liner is generally required, although it may be waived in the case of special inert materials. A daily soil cover, a final 2-foot soil cover, and reseeded are required. If average annual precipitation exceeds 25 inches, provisions must be made to intercept and treat the leachate.

WDOE regulates hazardous waste disposal under the Hazardous Waste Disposal Act (HWDA) of 1976. For regulatory purposes these wastes are categorized as "dangerous wastes" (wastes that present a hazard to human health, wildlife, or the environment due to short-lived toxicity, corrosivity, explosivity, flammability, or that generate pressure through decomposition or other means) and "extremely hazardous wastes" (wastes that are persistent in a hazardous form for several years or more, are highly toxic, present a significant environmental hazard, may be concentrated through the food chain, or may affect genetic makeup of man or wildlife). The process wastes from manganese nodule processing may contain certain substances that could lead to their designation as dangerous wastes or extremely hazardous wastes depending on the concentration and quantity and whether or not the potentially toxic constituents are inert. HWDA provides for the acquisition by the State of a single disposal site for wastes classified as extremely hazardous, while dangerous wastes can be disposed of under the County Disposal Site Permit program. HWDA also provides that WDOE set up a "waste exchange" for waste generators to find users for dangerous and extremely hazardous wastes in order to reduce the volume of wastes to be disposed of.

The State of Washington is in the process of developing regulations governing storage, treatment, and disposal of dangerous wastes. As part of its long-range goal, WDOE is seeking to revise its programs governing hazardous wastes to conform with RCRA guidelines in order to get EPA approval for administering the permitting program mandated under RCRA. This program will be administered by EPA until the State of Washington conforms with all its requirements. The proposed regulations include siting standards and performance standards for preventing degradation of groundwater, surface water, and air quality as well as for protecting flora and fauna outside the active portion of the site, reducing human health, aesthetic, and noise impacts, and using processes that recover the waste to the extent economically feasible.

California

Waste Disposal

Several State agencies specifically regulate land disposal of wastes. These include the State Water Resources Control Board (SWRCB) and its Regional Water Quality Control Boards (RWQCB's), the California Solid Waste Management Board (SWMB) and its local enforcement agencies, and the Department of Health Services (DHS).

The SWRCB formulates water quality control policy, pursuant to the Porter-Cologne Water Quality Control Act, Water Code Section 174 et seq., and also acts as the appellate body for matters on which the RWQCB's fail to act. Each RWQCB formulates and adopts regional water quality control plans, which are implemented by the adoption of waste discharge requirements. The RWQCB's have EPA approval to issue Federal NPDES permits, governed under Section 13376 of the California Water Code. A landfill or tailings pond that does not directly discharge into surface waters would not require an NPDES permit. However, if decant waters or runoff will be discharged, an NPDES permit will be required, and must be consistent with adopted

water quality objectives, the Areawide Waste Treatment Management ("208") Plan, and the Basin Plan for the project area, and with FWPCA's effluent limitations, national standards of performance, and toxic and pretreatment effluent standards.

In addition to issuing NPDES permits, the RWQCB's also administer a State program for water quality control, which generally issues waste discharge requirements that are more stringent than those required by EPA. In addition to regulating point source discharges, the State water quality regulations apply to discharges of wastes into closed systems such as containment ponds or landfills. Unless the RWQCB's can be convinced that the material being discharged is a stockpile of valuable materials rather than waste, these requirements will apply.

Underground injection wells must be certified by the California Division of Oil and Gas. Construction and operation must conform with the regulations, there must be no hydraulic continuity with usable groundwater and no passageways may be developed for movement of waste into usable aquifers or to the surface.

The State policy promulgated by the SWMB for solid waste management contains standards and criteria for location, design, operation, maintenance, and ultimate reuse of solid waste handling facilities. A solid waste facilities permit must be obtained from the SWMB by owners and operators of disposal sites. While hazardous wastes are handled in accordance with DHS regulations and approval of local agencies having jurisdiction, nonhazardous solid waste facilities permits are issued by county enforcement agencies operating under the SWMB, which must concur with the permit issuance.

In California a waste is assigned to one of three classification groups according to its components, and waste disposal sites are classified based on groups of wastes they can accept. Wastes containing toxic substances are classified as Group I wastes. Saline wastes that would threaten the groundwater quality and mine tailings from which toxic materials can leach would be considered Group I wastes. Thus, manganese nodule rejects from hydrometallurgical processes with high salinity from their seawater content would probably fall in this category. Group I wastes must be disposed of in a Class I disposal site, which is a site in which "complete protection is provided for all time for the quality of ground and surface waters from all wastes deposited therein and against hazard to public health and wildlife resources." The SWRCB summarizes Class I waste disposal sites as follows:

Class I - There must be no possibility of discharge of pollutant substances to usable waters. Artificial barriers may be used for the control of lateral waste movement only. Usable groundwater may underlie the site, but only under extreme cases and where natural geological conditions prevent movement of the wastes to the water and provide protection for the active life of the site. Inundation and washout must not occur. All waste groups may be received.

Limited Class I - A special case of Class I site is established where a threat of inundation by greater than a 100-year flood exists. A limitation is placed on the type and amount of Group I wastes that may be accepted.

Class I sites have very stringent waste discharge requirements, including limits on the quantity of wastes that can enter the site. They also must overlie naturally impermeable materials: an artificial liner is not considered an acceptable barrier to vertical migration in a Class I site. Because of the large quantity of waste involved, the applicant would have to apply for certification of a new Class I site if wastes were classified as Group I, or would have to remove hazardous substances from the wastes

and deposit them separately in a Class I site. A variance might be obtained for certain Group 1 wastes if the RWQCB decided that the wastes would not jeopardize water quality. Then the wastes could be disposed of in a Class II-1 site, which would be subject to less stringent waste discharge requirements. The SWRCB summarizes Class II-1 waste disposal sites as follows:

Class II-1 - These sites may overlie or may be adjacent to usable groundwater. Artificial barriers may be used for both vertical and lateral waste confinement in the absence of natural conditions. Protection from a 100-year frequency flood must be provided. Group 2 and 3 wastes can be accepted and under special conditions, certain Group 1 materials may be accepted.

Inert slags and inert tailings would be considered as Group 3 wastes and could be disposed of in a Class II-2 or Class III site (as well as Class I, Limited Class I, and Class II-1) as long as toxic components were removed. The SWRCB summarizes Class II-2 and Class III disposal sites as follows:

Class II-2 - These sites may have vertical and lateral continuity with usable groundwater but have features that provide for the protection of water quality. Group 2 and 3 wastes may be accepted.

Class III - These are sites where Group 3 wastes could under certain conditions be dumped directly into ground or surface water or where there is inadequate protection to water quality. Only Group 3 wastes may be accepted. Construction practices and facilities that could cause a discharge of soil or accelerate downstream transport of soil are also considered Class III disposal sites.

Waste discharge requirements would only be applied to Class III sites if water quality might be threatened during construction or operation.

Regulation of hazardous wastes falls under the jurisdiction of DHS, which, in order to protect the public health, wildlife, and the environment, establishes standards for handling, haulage, storage, use, processing, and disposal, and issues hazardous waste facilities permits and extremely hazardous waste facilities permits. A hazardous waste is defined as a waste material that is toxic, corrosive, flammable, an irritant, a strong sensitizer, or which generates pressure through decomposition, heat, or other means, and may cause substantial injury, serious illness or harm to humans, domestic livestock, or wildlife. Extremely hazardous wastes, included in the hazardous wastes category, are likely to result in death, disabling personal injury, or illness because of the quantity, concentration, or chemical characteristics of the waste. The hydrometallurgical and pyrometallurgical processing techniques for manganese nodules potentially could produce substances currently included on the lists of hazardous and extremely hazardous wastes. A variance from hazardous waste regulations can be requested from DHS, which must grant a variance if it finds that the waste does not create a hazard. An application can be made for classification of the waste as nonhazardous if laboratory tests can be provided showing why the waste should not be classified as hazardous.

All hazardous waste facilities must obtain a hazardous waste facility permit or a variance in order to operate. This permit will not be issued unless the RWQCB waste discharge requirements are met and the operator has ensured that the handling and disposal methods are designed to avoid errant discharges, movement of wastes outside the disposal area, undue exposure or contamination of any person, and hazard to public health and safety, wildlife, or domestic livestock. DHS reserves the right to attach conditions to the permit. In the case of manganese nodule rejects, this could include

such conditions as requiring secondary recovery of manganese and other metals not recovered in the three-metal process.

Each county prepares a comprehensive, coordinated solid waste management plan that includes a program for handling and disposal of hazardous wastes. In order to be effective, these plans must be certified by the SWMB as consistent with State solid waste management policy. All solid waste disposal, transfer (including pipelines), or processing facilities must conform to the county solid waste management plans. Because none of the county plans allow for disposal sites on the scale of a manganese nodule waste disposal facility, the need to amend the county plan is a certainty. Such an amendment would require certification by the SWMB.

Texas

Waste Disposal

Liquid waste discharges are regulated by a dual State-Federal monitoring and enforcement program under the Department of Water Resources (DWR). The State water quality standards generally are equivalent to or more stringent than the Federal standards. NPDES permits are not issued by the State, but applicants are referred to the regional EPA office. A similar program is administered at the state level. The DWR also issues underground injection permits under the Injection Well Act. The rules under the act set forth design and performance requirements.

Industrial Solid Waste Management Regulations have been promulgated under the Texas Solid Waste Disposal Act of 1969. The lead agency for industrial solid waste disposal is DWR, while the Department of Health regulates municipal solid waste disposal. DWR has drawn up a series of technical guidelines related to industrial solid waste management, which are advisory in nature. These guidelines include classification of wastes; site selection and evaluation; landfills; ponds and lagoons; monitoring systems and leachate collection; supporting facilities such as roads, fencing, litter control, and spill control; and records for waste disposal and monitoring. They seek to prevent conditions that are prohibited under the regulations. The classification system for solid wastes in Texas is as follows:

Class I Wastes: Any industrial solid waste or mixture of industrial solid wastes that, because of its concentration or physical or chemical characteristics, is toxic, corrosive, flammable, a strong sensitizer or irritant, a generator of sudden pressure by decomposition, heat, or other means, and may pose a substantial present or potential danger to human health or the environment when improperly treated, stored, transported, or disposed of or otherwise managed, including hazardous industrial waste.

Class II Wastes: Any industrial solid waste or combination of industrial solid waste that cannot be described as Class I or Class III as defined in this regulation.

Class III Wastes: Inert and essentially insoluble industrial solid waste, usually including but not limited to materials such as rock, brick, glass, dirt, and certain plastics and rubber, etc. that are not readily decomposable.

Under the Industrial Solid Waste Management Regulations, "no permit shall be required for the onsite storage, processing, or disposal of industrial solid waste unless such waste is hazardous industrial waste," listed as a hazardous waste by EPA. Onsite is defined as being "within the property boundaries of a tract of land owned or

otherwise effectively controlled by the owners or operators of a particular...mining operation...from which the waste results or is produced, and which tract of land is within 50 miles" from that operation. Thus if the wastes from manganese nodule processing are not classified as hazardous and if the operator controls the land where transport and disposal will be taking place, no permit will be required for storage, processing, or disposal of the solid waste. If the waste would be considered by EPA as hazardous, and is thereby a Class I waste, a permit will be required. Application must be filed with DWR.

On-site waste disposal operators must notify DWR of their intentions to dispose of wastes on their site. DWR may request information regarding waste composition, management methods, specifications, or geology in order to determine compliance with regulations. Any waste disposal activities on a tract of land must be recorded in the deed for that land. Shipping and reporting procedures applicable to generators and carriers of all wastes and to receivers of Class I wastes must be followed. The procedures vary for different classes of wastes.

The hazardous waste program in Texas has been approved by EPA for Phase I interim authorization to enforce the interim status standards for existing facilities, and the State has applied for Phase II approval to conduct the permitting program for existing and new hazardous waste facilities.

In addition to the State permitting process, counties also can require that a waste disposal operation obtain a license. County license requirements must be at least as stringent as State permit requirements and must meet with approval of the appropriate State agency.

Hawaii

Waste Disposal

The Hawaii Environmental Quality Law (EQL) section on solid waste pollution provides that no person shall operate a solid waste disposal site without first securing a permit from the Hawaii Department of Health (DOH). However, there is some ambiguity in the definition of solid waste in terms of whether or not a slurried mining waste would be considered solid waste. If the waste were considered hazardous, however, the Solid Waste Management Control Regulations would apply. These regulations require that an applicant for a permit employ the best practicable technology in its facility design, and they include operating and design standards for waste disposal facilities. The standards for hazardous waste disposal define hazardous wastes as "any waste or combination of wastes which pose a substantial present or potential hazard to human health or living organisms because such wastes are nondegradable or persistent in nature, or because they can be biologically magnified or because they can be lethal, or because they may otherwise cause or tend to cause detrimental cumulative effects."

Hawaii's DOH also issues NPDES permits for effluent discharges, which would be required for any water collected from the site to be discharged into surface waters. The discharge must not cause a violation of any DOH rules and regulations and must not endanger the maintenance or attainment of applicable water quality standards. Hawaii's water quality standards are currently subject to approval by EPA.

Important Regulatory Issues at Each Representative Site

Any of the regulations identified in the preceding sections and in appendix C can, under certain circumstances, become significant; however, considering the nature of the rejects, the waste disposal techniques, and the characteristics of the five representative sites, the following issues are likely to be most important in the selection and permitting of a site for nodule reject disposal:

All sites

- o toxicity of the rejects from hydrometallurgical processes (RCRA)
- o RCRA exemption for mining and processing wastes

Cherry Point, Washington

- o required leachate collection system for solid wastes (SWMRRA)
- o treatment of rejects as dangerous or extremely hazardous wastes (HWDA)
- o pending modifications to HWDA

Casmalia, California

- o treatment of nodule rejects as Group I wastes
- o SWRCB requirements for Class I disposal sites
- o Disposal of nodule rejects at Class II-I disposal sites
- o TSP non-attainment areas designation (CAA).

All Sites

At all five sites (except possibly the California site, where State hazardous waste regulations are more restrictive than Federal regulations) the EPA classification of the rejects as hazardous or nonhazardous waste is important because it determines the feasibility of the project and the disposal regulations that apply. Although definitions of hazardous (or dangerous) wastes differ by State, the characteristic of toxicity is a common consideration in each of the definitions. Other characteristics that lead to a hazardous classification are not applicable to rejects. Slags, which are inert, are not likely to be classified as hazardous at any site.

Toxicity is most specifically defined by EPA regulations, so if we assume that the EPA toxicity test procedures would be accepted by the States (again with the exception of California) then the specifics of the tests and the results for nodule rejects become a significant regulatory issue.

A complicating factor and an additional issue regarding EPA and hazardous waste is the current exclusion from RCRA hazardous waste regulations of solid wastes from extraction, beneficiation, and processing of ores and minerals. The results of a study to determine whether this exclusion is justified and uncertainty as to whether processing of ocean minerals would be included in the exclusion could become important issues for nodule reject disposal.

Texas is pursuing authorization for an EPA-approved hazardous waste program, and Hawaii does not have unique regulatory requirements for waste disposal that would raise issues not covered under Federal regulations.

Cherry Point, Washington

The hazardous waste regulations for the State of Washington are currently undergoing revisions and public hearings, and any hazardous waste disposal issues that are discussed here would have to be reevaluated against the revised regulations when they are adopted.

In Washington where rainfall exceeds 25 in/yr (63.5 cm/yr), as it does at Cherry Point, a leachate collection system is required for solid waste disposal sites. Assuming tailings would be treated as solid waste but not as a hazardous waste, this regulation would impose significant additional financial and technical constraints on a nodule reject disposal facility. The scale of a nodule reject facility is larger than typically anticipated for a solid waste disposal facility, and it is clear from the regulations that mineral tailings were not specifically considered in developing the solid waste regulations.

Classification of nodule rejects as extremely hazardous under current Washington regulations would make a nodule waste disposal in the state impractical since the only designated extremely hazardous waste site--the Hanford reservation--has neither the capacity nor an advantageous location to serve a nodule processing plant in the regions considered likely. Classification as dangerous waste would place the permitting decisions with the county through their solid waste management plans. No county has considered large mineral waste proposals within their solid waste management plans. Only the Colville Indian Reservation Solid Waste Management Plan has discussed solid waste from a large mining project (AMAX's Mount Tolman project), and then only in a general way.

The likely classification according to HWDA of rejects from hydrometallurgical process is not apparent at this time.

Casmalia, California

The requirements of the California SWRCB for nonsewerable waste disposal to land create a unique regulatory situation. From the examples in the regulations, nodule rejects from hydrometallurgical processes would probably be classified as Group I wastes either because they are "substances from which toxic materials can leach such as...mine tailings" or because "fluid containing dissolved salt concentrations in excess of quality required for irrigation must be prevented from percolating to fresh groundwater" (121). Although results of an EP toxicity test would possibly be considered in determining whether nodule rejects are classified as Group I wastes, they could be classified as Group I wastes by virtue of their origin or sea salt content even if they did not exhibit EP toxicity.

A second unique aspect of the SWRCB rules is that, at Class I disposal sites, engineered measures such as liners and leachate control systems are not allowed as a substitute for natural conditions such as absence of usable (less than 10,000 mg/l TDS) groundwater, and geological formations that prevent vertical hydraulic continuity between the wastes and usable groundwater. This shifts the issue from appropriate containment design to appropriate geology, and it places all facilities that require Class I disposal sites in competition for a limited number of intrinsically suitable sites near the coast. A State Hazardous Waste Siting Council has been proposed as a means to solve this problem (79). A siting program for southern California is also underway (184).

Under special circumstances, specific Group I wastes can be disposed of in Class II-I disposal sites, which can have liners and other engineered protection for underlying usable groundwater; however, this involves the discretion of Regional Boards and a corresponding uncertainty in the permitting process.

Air quality is a major regulatory concern in Southern California although not always for TSP, which are the relevant concern for disposing of mineral wastes. Because of agriculture and mining near Casmalia, the part of Santa Barbara County containing the representative site is a non-attainment area for particulates. Currently revisions to CAA are being considered that include distinction based on sizes of particulates. The TSP non-attainment status of western Santa Barbara County is already being contested and is currently a regulatory issue.

RECOMMENDATIONS

Monitoring Requirements

No unusual monitoring requirements specific to manganese nodule reject disposal were identified during this study. For slag disposal, after testing to determine that the materials are inert, disposal could be carried out with very little monitoring, other than visual inspection, in all of the siting regions. For hydrometallurgical process slurries monitoring typical of solid waste and tailings disposal sites would be the minimum requirement. These monitoring practices focus on maintaining physical containment of the wastes and separation from the environment. Should toxic leachates be suspected or the waste be classified as hazardous, monitoring requirements would be significantly upgraded to those typical of hazardous waste disposal sites.

For the stricter monitoring of disposal sites, monitoring would consist of predisposal monitoring, surveillance, water level records, leachate volume measurement, seepage collection measurements, monitoring wells upgradient and downgradient, chemical analyses of leachate and surrounding groundwater and surface water, and visual and instrumental particulate monitoring in dry climates. Groundwater monitoring would be expected to be similar to EPA Interim Status Standards for Owners and Operators of Hazardous Waste Facilities (40 CFR 265 Subpart F).

Predisposal monitoring would establish an environmental baseline indicative of effects caused by sources unrelated to the reject disposal site and to verify the presence or absence of usable groundwater and surface water. During the site selection and permitting process the presence of species with special status and other important environmental features would have been identified. Where these are concerns, the monitoring may include a program to confirm that there are no adverse effects.

Surveillance would ensure that obvious seepage, weakness of parts of retention structures, severe dusting, and other conspicuous problems could be corrected. Monitoring of embankments would be typical of water-type dams because the retention structures would not be made of rejects.

Water level records indicate the proximity to groundwater under the disposal area. Measurement of leachate (or liquid) volume indicates the water level (hydraulic gradient) acting against natural or artificial barriers and also the water level (phreatic surface) in the embankments.

Chemical analyses for monitoring would focus on toxic elements and TDS particularly chlorides.

All of the above requirements are typical of strict solid waste disposal monitoring and the principal difference for a nodule reject disposal site would be the scale of the facility.

Needs for Further Study

Although we have identified analogs to nodule processing and waste disposal from processing and disposal of wastes from terrestrial ores, primarily nickel laterites, there is not enough published information available on disposal of wastes from these

operations to permit an accurate assessment of environmental effects. Even if it could be assumed that the analogy were perfect and that the nodule rejects would behave exactly as the laterite tailings, many questions could not be answered at this time from the available literature on laterites.

The most significant question to be answered is: Are nodule rejects toxic (hazardous) as defined by EPA? The only really satisfactory answer to this question would come from subjecting rejects from a commercial manganese nodule processing plant to the EP toxicity test (40 CFR 261 Appendix II) and comparing the results to the standards in 40 CFR 261.24. Less satisfactory but nevertheless very useful information would be the results of the EP toxicity test procedure on rejects from a bench-scale process or onshore test unit. Leaching and toxicity tests on tailings from commercial laterite processing would also provide valuable information, although the results would have to be interpreted cautiously because of differences in the matrix and relative iron and manganese content. We would recommend that this extraction procedure be performed on whatever reject samples are to be tested within the Avondale study.

The importance of the EP toxicity test is regulatory; that is, it determines whether hazardous waste or solid waste regulations would be applied by EPA. More significant effects would also be expected for a toxic waste. Hazardous waste facilities would require a more sophisticated containment, including a compacted clay or artificial liner where the site overlays usable groundwater and the geology of the site does not provide a natural barrier (such as shale) to vertical movement of leachate. Monitoring would also be of more concern and the permitting process would be expected to take longer for a hazardous waste disposal site.

The EP toxicity test procedure is based on extraction in deionized water with adjustment using acetic acid to pH 5.0 $\pm$ 0.2 up to a maximum addition of 4 ml of acid per gram of solid. Solutions of solids and deionized water with pH less than 5 are not adjusted. ASTM has developed an alternate procedure, Standard Test Method for Shake Extraction of Solid Waste with Water (ASTM D 3987-81), for conditions "where solid waste is the dominant factor in determining pH of the extract." Because of possible questions as to the applicability of these tests to simulating leachate production from a solid waste disposal site, we would recommend that both tests be run and compared. The comparison of the tests would indicate the effect of pH on leaching.

Chemical test methods for analyzing extract contaminants used in determining EP toxicity--antimony, arsenic, barium, cadmium, chromium, lead, mercury, nickel, selenium and silver--are specified in 40 CFR 261 Appendices II and III and the incorporated references. (Mercury and silver are of less concern because of low concentrations in rejects relative to standards.)

In addition to the EP toxicity test and the ASTM shake extraction procedure, chemical and mineralogical analyses of the rejects are required in order to identify the forms in which toxic and other important elements would occur in the nodule rejects. Additional specific elements that should be analyzed for their percent by weight in the rejects and their concentration (mg/l) in leachate test extracts are antimony, beryllium (low concentration vs. standard), copper, nickel, thallium and zinc (TSCA priority pollutants not on EP toxicity list); cobalt and manganese (other unrecovered value metals in the nodules); lanthanum; and vanadium. Standard methods of EPA, ASTM, and the American Public Health Association are available for all of these metals. Mineralogical analysis would focus on clays. This would confirm whether the estimates in this report are correct. Identifying the form in which these elements occur would

also provide insight into the mechanisms by which they could be mobilized and controls that would be effective in containing them.

Regarding the physical properties of the rejects, complete testing of sample rejects from each of the processes would include:

- o slurry density (resulting from process),
- o grain-size (particle-size) analysis (ASTM D 422),
- o specific gravity (ASTM D 854),
- o liquid limit (ASTM D 423)
- o plastic limit/plasticity index (ASTM D 424),
- o soil classification (ASTM D 2487),
- o permeability,
- o maximum density/optimum water content (ASTM D 698 and D 1557),
- o triaxial shear strength (ASTM D 2850),
- o rate/amount of consolidation (ASMT D 2435), and
- o column settling (drained/undrained).

Although we have indicated less uncertainty and concern about slags, similar physical (and chemical) property testing should be performed to confirm the assertions in this report.

The most basic physical property analysis would be to determine the particle-size distribution. Although estimates from laterites are provided in this study, the particle sizes reported are by no means definitive. Particularly for the four-metal hydrometallurgical processes, which have less direct analogies, the particle sizes may be finer than the 100% passing sieve numbers that are given.

The particle-size distribution is a significant indication of other properties and of the potential effects of waste disposal. Wind erosion susceptibility depends on the percent of the rejects finer than the critical size for wind transport. Density and drainage are also related to texture as indicated by grain-size distribution.

In terms of determining the effects of reject disposal, the settled volume of material and the size of the site required to contain it are significant factors. There is currently no consistency among the various reports that have given values for nodule waste disposal site area. Dames and Moore (80) estimated 40 ha/yr (100 acres/yr), 12.2 m (40 feet) deep for the high temperature sulfuric acid process assuming an in-place dry density of .80 mt/cu m (50 lb/cu ft). Jenkins (176) estimated 100 ha/yr, 2.1 m (7 feet) deep for the reduction/ammonia leach process, which would indicate a dry bulk density of 1.22 mt/cu m (76 lb/cu ft). The typical three-metal process settled densities used in this report are equivalent to 1.15 mt/cu m (72 lb/cu ft) dry bulk density. Inconsistencies result from differences in assumed bulk density (the largest variability occurs here), use of different processes (and amount of waste) in calculating the area required,

and different assumed average heights of solid fill. The effect of terrain has typically been ignored although terrain and average height of fill are closely related.

In order to accurately estimate density, laboratory testing to measure the settled density of rejects for each process is required. Column settling and consolidation rate testing would also be useful to establishing how rapidly the wastes would stabilize for reclamation.

Because the rejects other than slags are not expected to be suitable construction material, the geotechnical properties that are of most concern are those that indicate support for vehicles during reclamation work, primarily density and shear strength as functions of void ratio (time). The angle of repose of the rejects at various water contents and their Atterberg limits would indicate their probable behavior during a catastrophic release.

Because potential sites include both areas where water supply is critical and areas where evaporation rates are much lower than rainfall, the behavior of the rejects in slurry form and the minimum water content required to maintain pumpability would be important areas for further study. In the first case, use of water for hydraulic transport could possibly be reduced; in the second case, excess water to be evaporated or injected could be reduced. Slurry behavior is also important for deep disposal. Slurry testing performed by the Colorado School of Mines Research Institute (32) is an example of appropriate testing.

From the process viewpoint, this report indicates that manganese recovery from the three-metal hydrometallurgical process is a technically and economically viable option but that flow sheets are not available. As this process appears to be likely, as well as the five processes previously identified, it would be desirable to obtain comparable information and to develop laboratory samples from bench-scale processes. This may be complicated by the lack of information that would be necessary to construct integrated process flow sheets.

Although the emphasis of this study is on rejects--leached tails, slags, and fused salts--other manufacturing wastes would be produced that would have unique characteristics because they originate from manganese nodules. These include smelting dusts, tank house slimes, and residues from liquid ion exchange steps. These types of waste are incompletely characterized at present. Where these wastes are present in substantial quantities, further research would be warranted on their composition, the concentration of toxic elements, and safe disposal requirements.

We have focused on needs for further study that apply to the types of process rejects and the processes. Developing needs for further study at representative sites would in most cases be so specific that study would be premature. A possible exception to this is the proposed use of tailings as land extenders, which is being studied by the University of Hawaii. This is related to the possible toxicity of the hydrometallurgical tailings as well as the composition of the native soils. As identified in the environmental assessment, the combination of high rainfall and extremely pervious geologic formations, would make conventional slurried waste disposal difficult in wet parts of Hawaii, and innovative approaches may have to be tried.

The needs for testing and further study that we have identified can be summarized approximately in order of relative importance as follows:

Primary research

- o EP toxicity testing of three- and four-metal hydrometallurgical tailings;
- o ASTM shake extraction testing of three- and four-metal hydrometallurgical tailings vs. EP toxicity criteria;
- o physical property testing of three- and four-metal hydrometallurgical tailings, especially particle-size distribution, settled bulk density, and rate of consolidation;
- o other chemical property testing for hydrometallurgical process rejects;
- o confirmation of predicted physical and chemical characteristics of slags;
- o development of flow sheets and reject characteristics analysis for three-metal processes with manganese recovery from tailings; and
- o physical and chemical characteristics of manufacturing wastes unique to nodule processing;

The first two tests above would be appropriate for samples of rejects presently available from industry and government process simulations. The remaining tests are better suited to fresh, pilot-scale rejects from a commercial development program. Only then would the information necessarily be useful; otherwise the results would have to be interpreted with great caution as to differences between the bench-scale process and a commercial operation.

Development of flow sheets for manganese recovery from tailings depends on industry interest and progress in pursuing this option.

Supplementary research

- o slurry rheology for hydrometallurgical process wastes; and
- o innovative techniques for disposal of slurried wastes in extremely wet climates.

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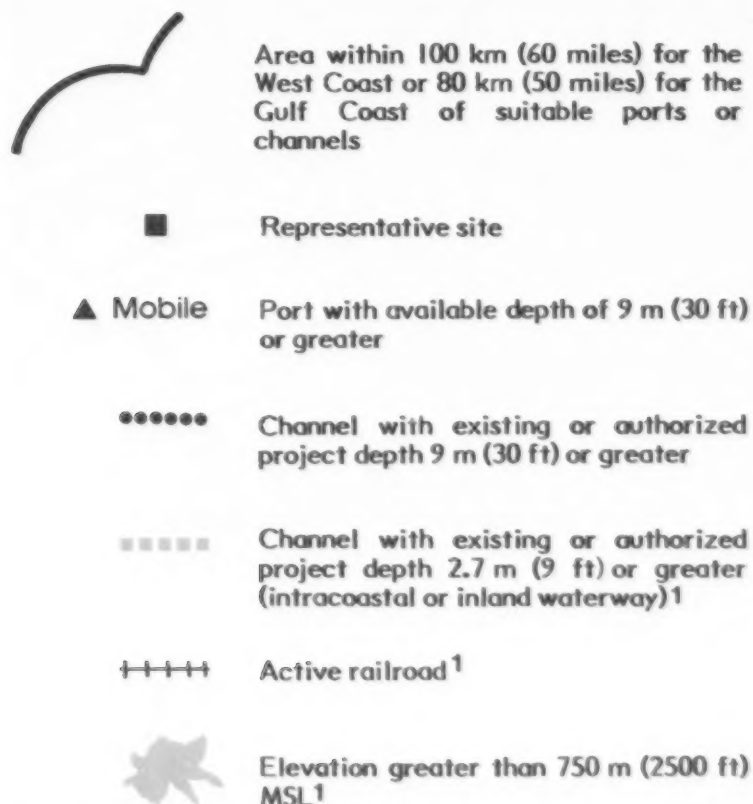
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APPENDIX A - THE SITING REGIONS

The area of maximum commercial interest for first generation manganese nodule mining operations is shown in figure A-1. Based on the location of this area in relationship to available port facilities and potential port locations, five siting regions were considered in this study: Hawaii wet climate (figure A-12), Hawaii dry climate (figure A-12), the Pacific Northwest (figures A-2 and A-3), Southern California (figure A-6), and the Gulf of Mexico region (figures A-7 through A-11). Two additional regions--Northern California (figure A-4) and the San Francisco Bay area (figure A-5)--have also been identified in previous studies as representative of possible sites for manganese nodule-related activities but are not specifically discussed in this report. Maps of all seven regions are included in this appendix. These maps show the principal criteria used in defining the limits of the five siting regions for this study according to this legend:



¹ Only shown within the limits of the siting regions

Additional information provided for this appendix are the port and channel data found in table A-1.

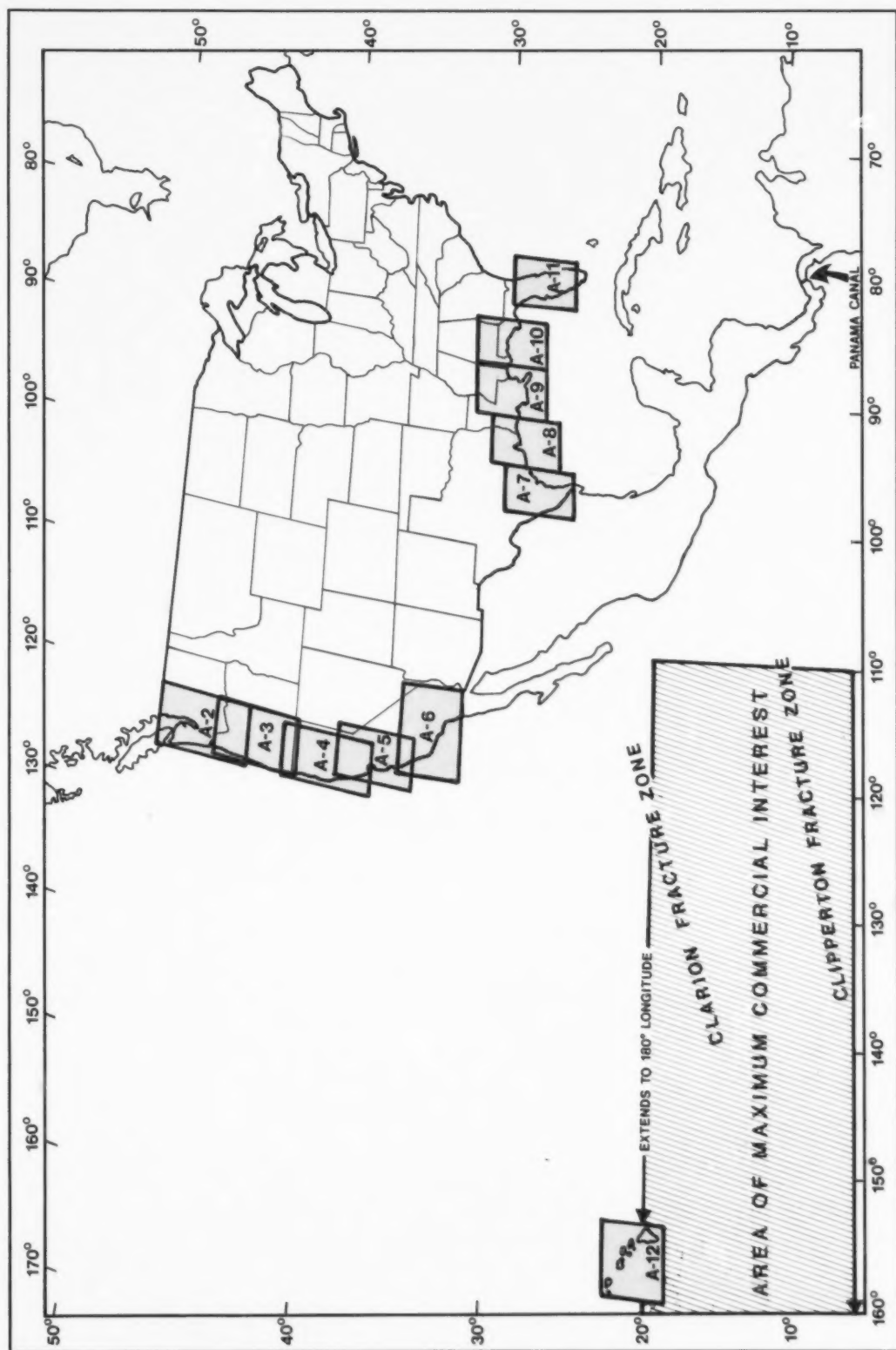


FIGURE A-1. - Index map for the siting region maps.

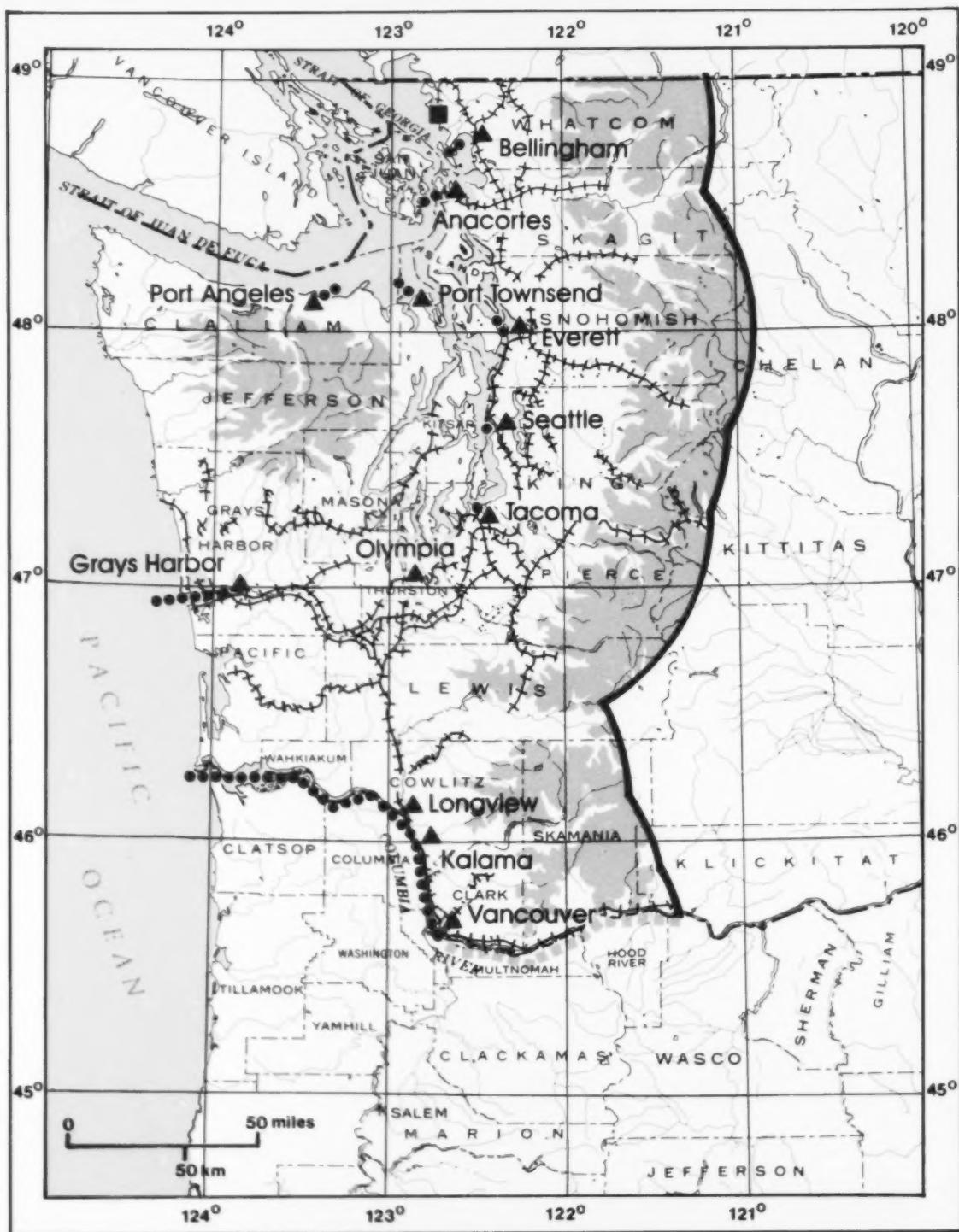


FIGURE A-2. - The Pacific Northwest siting region - Washington.

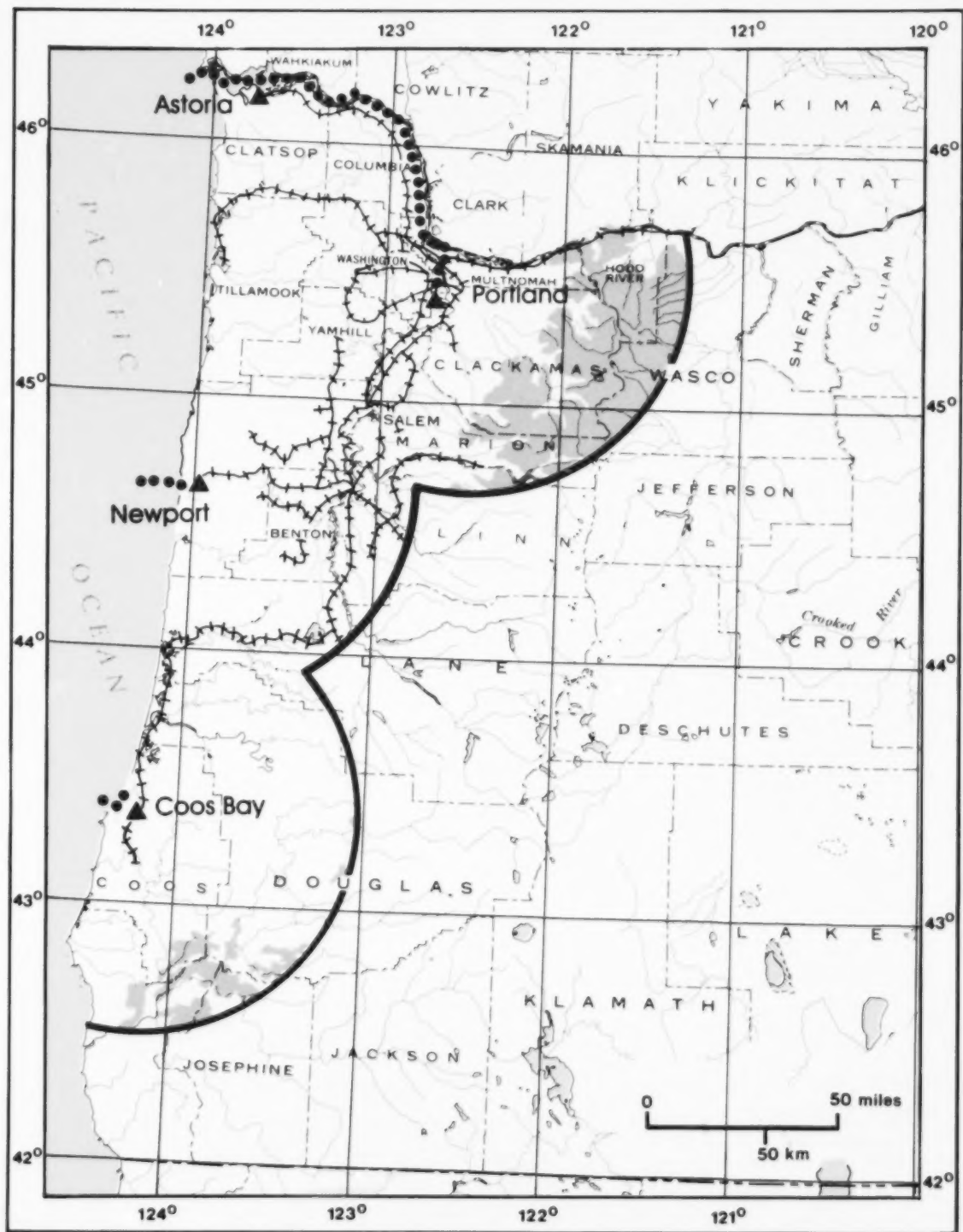


FIGURE A-3. - The Pacific Northwest siting region - Oregon.

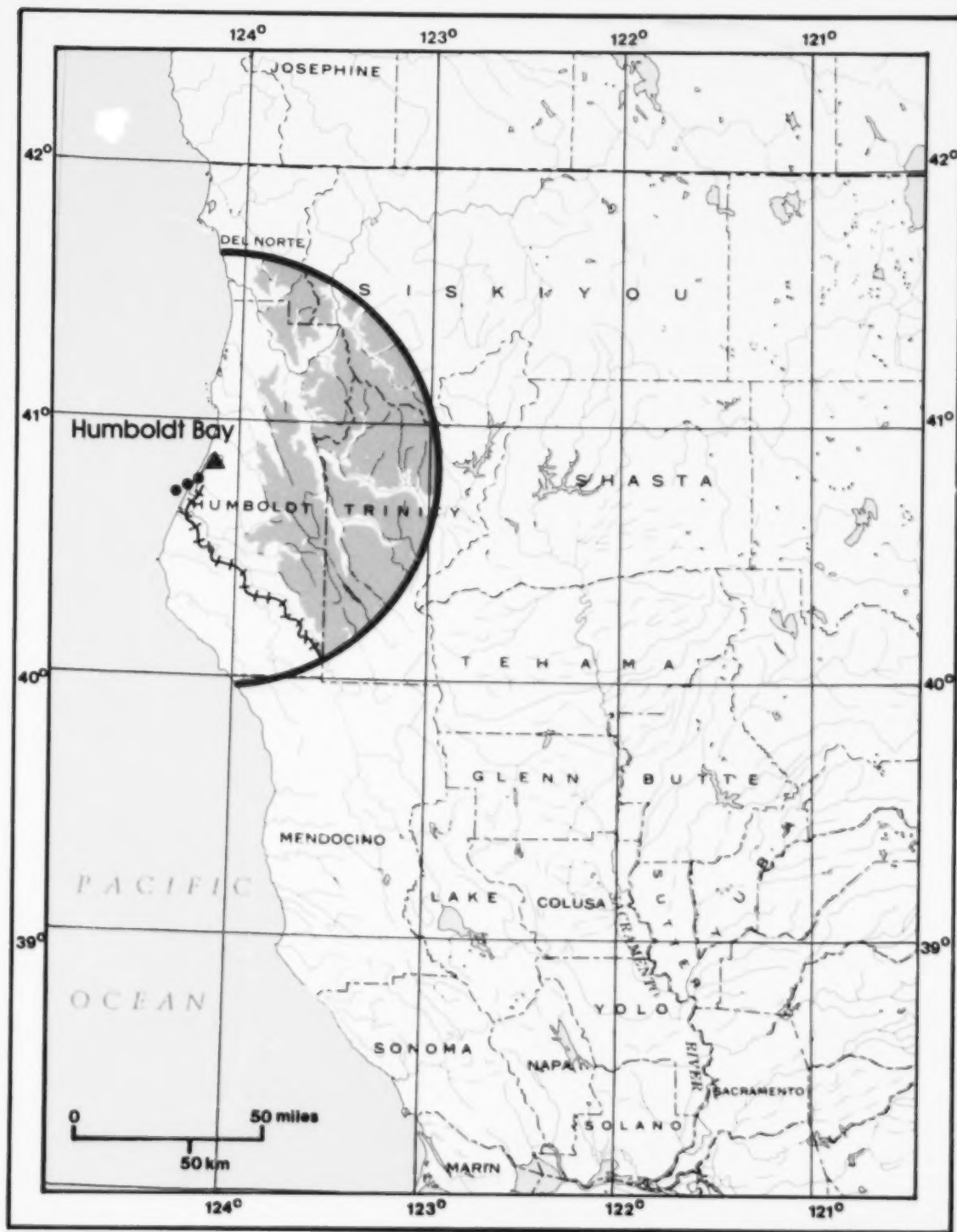


FIGURE A-4. - The Northern California siting region.

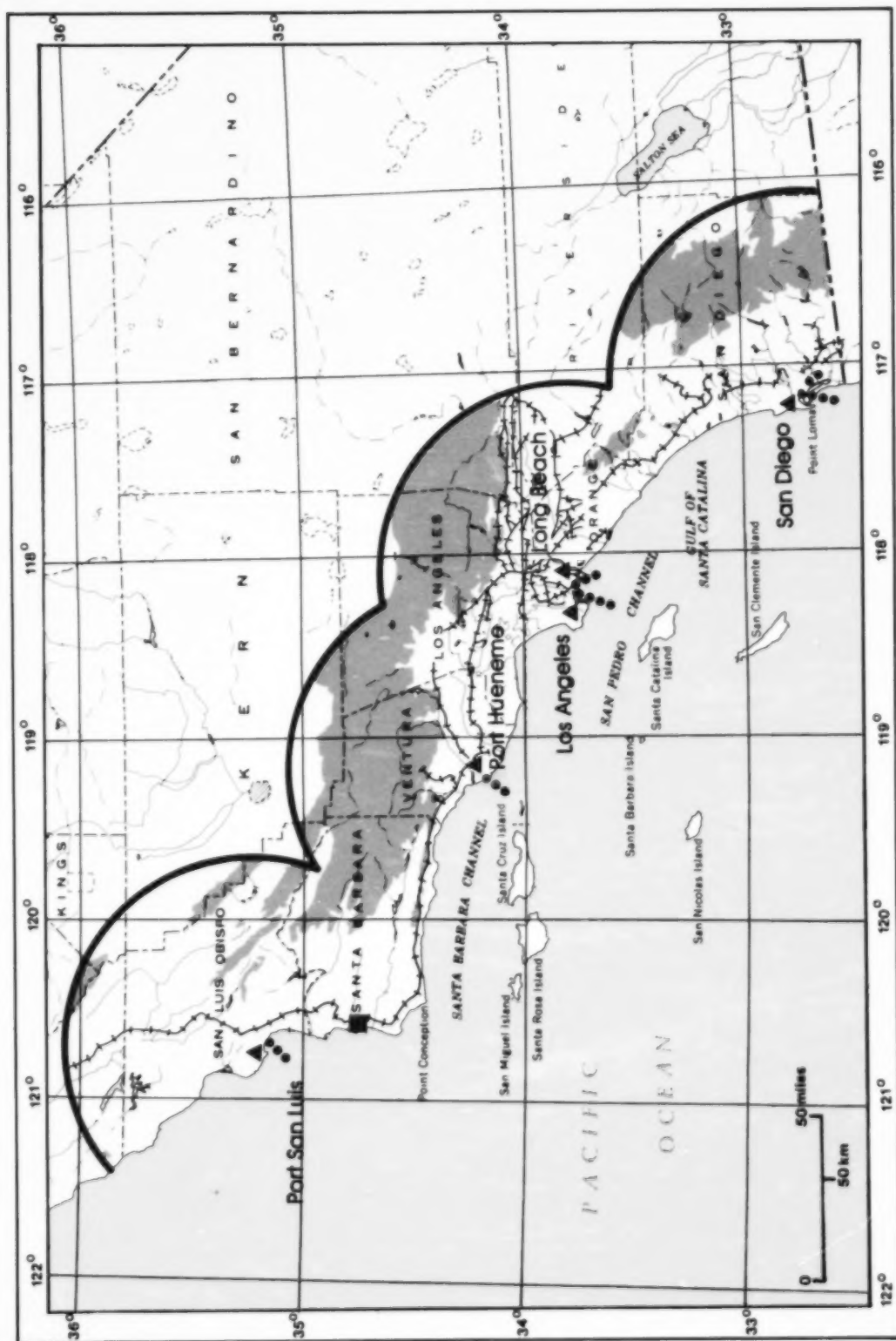


FIGURE A-6. - The Southern California siting region.

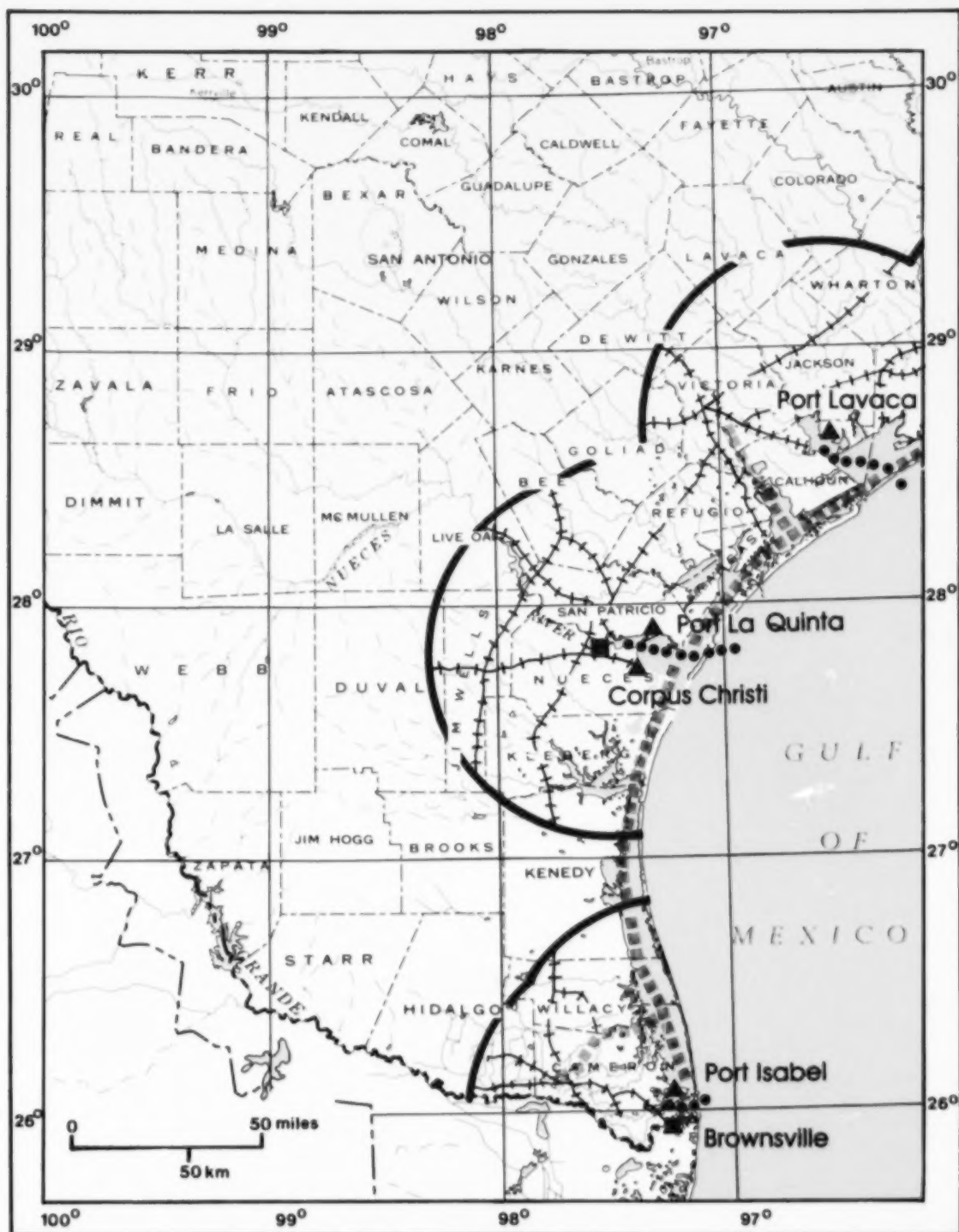


FIGURE A-7. - The Gulf of Mexico siting region - Brownsville to Port Lavaca, Texas.

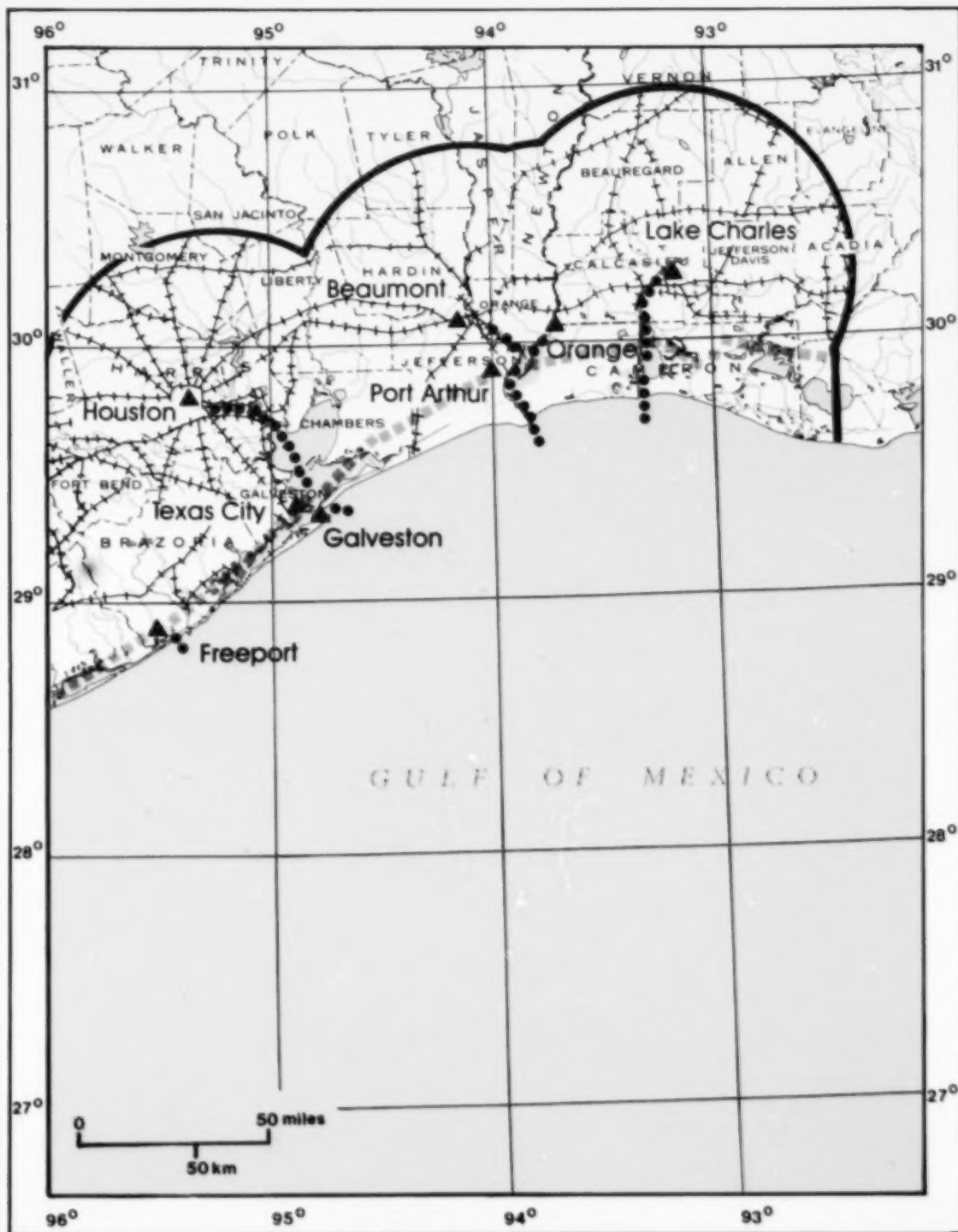


FIGURE A-8. - The Gulf of Mexico siting region - Freeport, Texas, to Lake Charles, Louisiana.

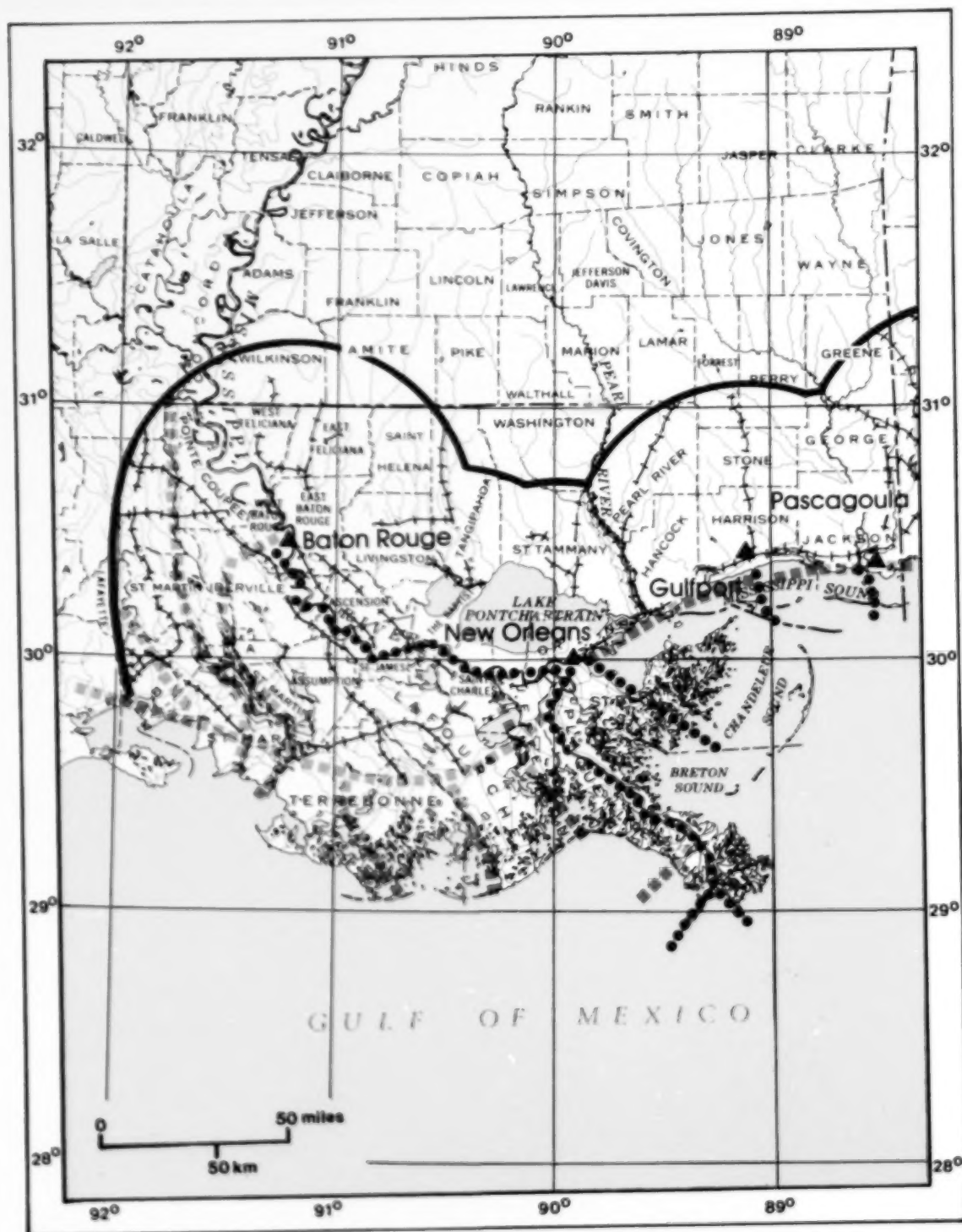


FIGURE A-9. - The Gulf of Mexico siting region - Baton Rouge, Louisiana, to Pascagoula, Mississippi.

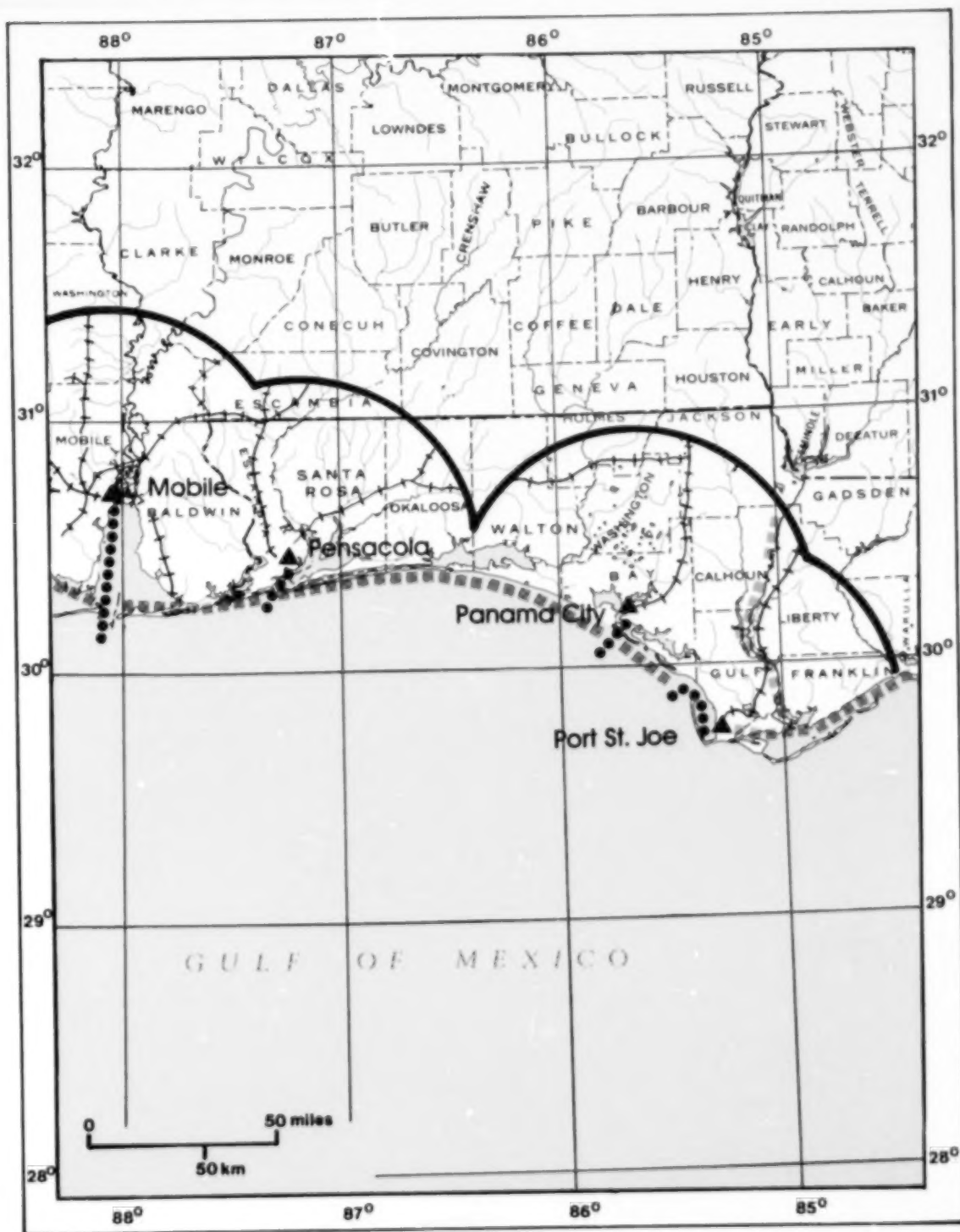


FIGURE A-10. - The Gulf of Mexico siting region - Mobile, Alabama, to Port St. Joe, Florida.

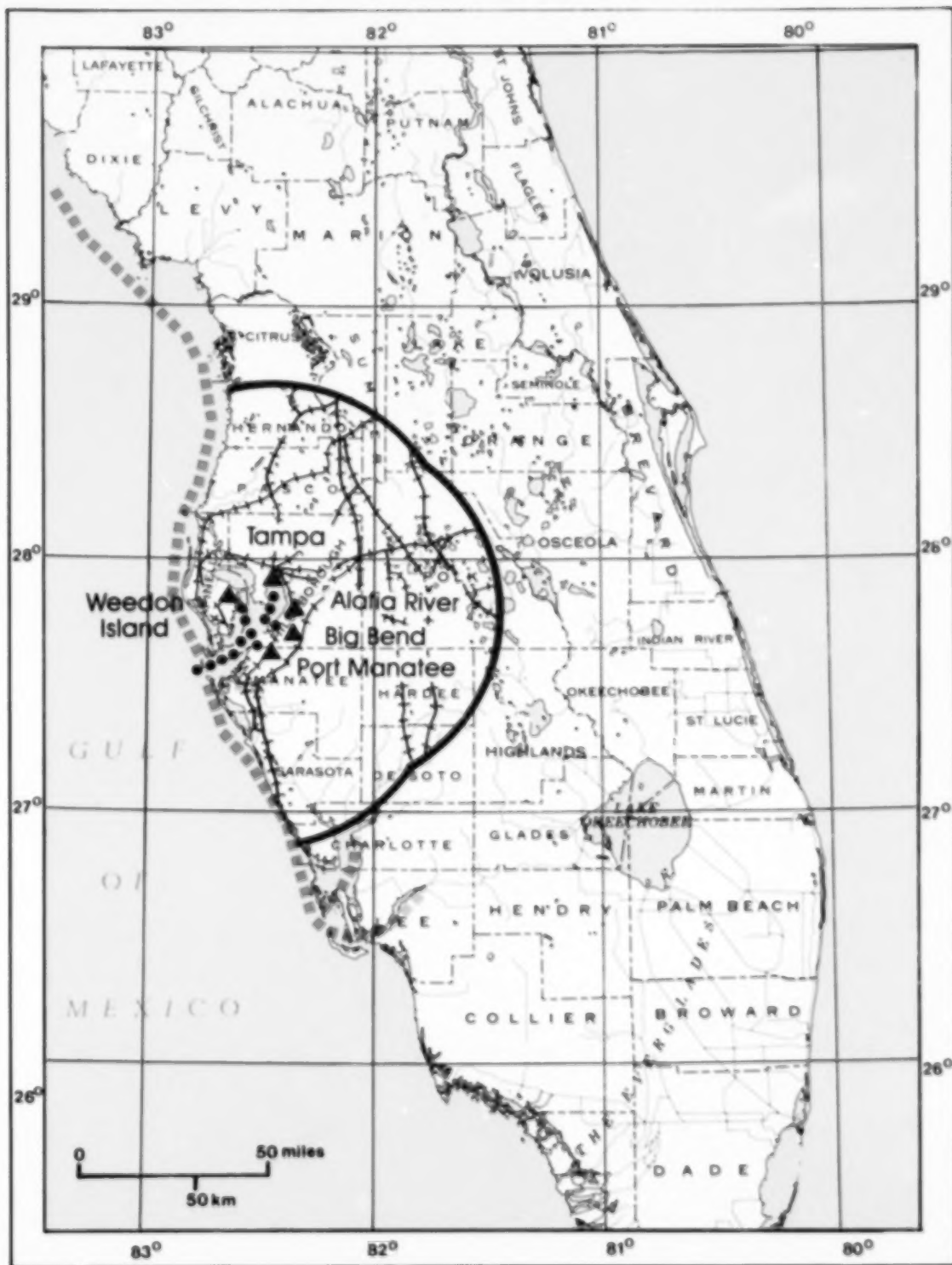


FIGURE A-II. - The Gulf of Mexico siting region - Tampa, Florida.

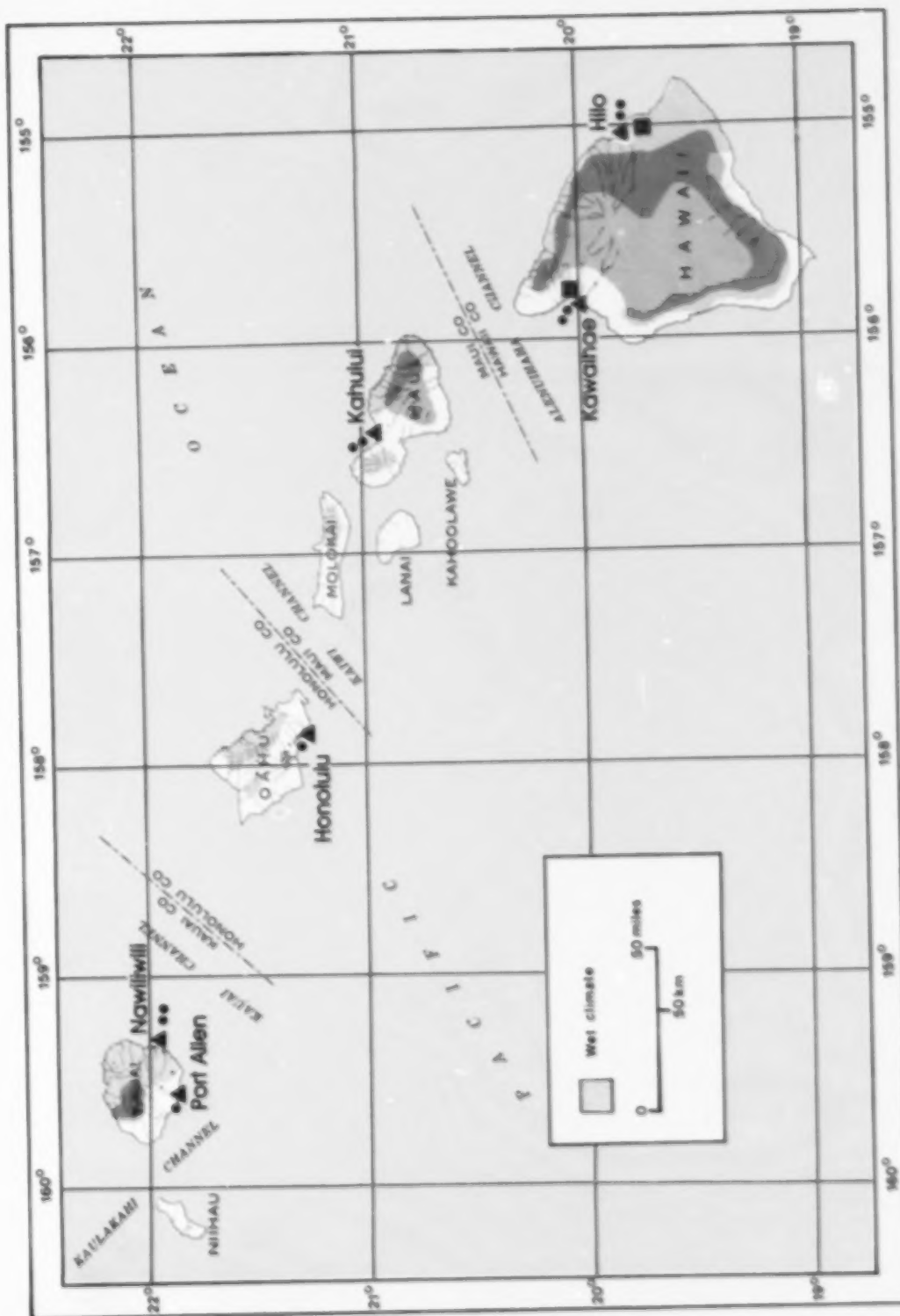


FIGURE A-12. - The Hawaii wet climate and dry climate siting regions.

TABLE A-1. - Port and channel information

Siting region	Port	Authorized project depth, feet	Controlling or reported depth, feet	Sailing distance from DOMES Site B, nautical miles ¹
Pacific Northwest...	Puget Sound ²			
	Port Angeles.....	NAP	90-180 harbor; to 45 alongside	2,435
	Port Townsend.....	NAP	30-120 harbor; to 30 alongside	2,467
	Bellingham.....	30	30	2,489
	Anacortes.....	NAP	33+	2,480
	Everett.....	NAP	28+	2,498
	Seattle.....	34	34+	2,504
	Tacoma.....	35	30-50 alongside	2,524
	Olympia.....	30	40-45 alongside	2,548
	Grays Harbor.....	30		2,310
	Columbia River.....	340	40	2,263 to mouth
	Astoria.....		35 alongside	2,275
	Longview.....		30-38 alongside	2,320
	Kalama.....		34-40 alongside	2,326
Northern California..	Vancouver.....		35-40 alongside	2,355
	Portland (Willamette River).. Newport.....	40 40/30	To 40 alongside 27 alongside	2,360 2,212
	Coos Bay.....	45/35	30-35 alongside	2,166
	Humboldt Bay.....	40/35	To 31 alongside	2,077

See footnotes at end of table.

TABLE A-1. - Port and channel information - Continued

Siting region	Port	Authorized project depth, feet	Controlling or reported depth, feet	Sailing distance from DOMES Site B, nautical miles ¹
San Francisco Bay Area....	San Francisco.....	55	45	1,950
	Oakland.....	35	35	1,953
	Redwood City.....	30	30	1,977
	Richmond.....	35	35	1,961
	Benicia.....	30	30	1,987
	Pittsburg.....	30	30	1,977
	Stockton.....	30	30	2,025
	Sacramento.....	30	30	2,028
	Port San Luis.....	30	30	1,842
Southern California..	Port Hueneme.....	30	25-31	1,784
			36 (channel)/	
			31 (basin)	
			40+	
	Los Angeles.....	45/40	35+	1,750
	Long Beach.....	35	35	1,751
	San Diego.....	42/35	35	1,700
	Brownsville Area			
	Brownsville.....	36	36	4,985
Gulf Coast....	Port Isabel.....	36	36	4,972
	Corpus Christi Area			
	Corpus Christi.....	45	45	4,930
	Port La Quinta.....	45	45	4,925
	Port Lavaca-Point			
	Comfort.....	36	36	4,909
	Freeport.....	30	30	4,897
	Galveston Area			
	Galveston.....	40	40	4,874
	Texas City.....	40	40	4,877
	Houston.....	36	36	4,918

See footnotes at end of table.

TABLE A-1. - Port and channel information - Continued

Siting region	Port	Authorized project depth, feet	Controlling or reported depth, feet	Sailing distance from DONES Site B, nautical miles ¹
Gulf Coast....	Port Arthur Area			
	Port Arthur.....	40	40	4,868
	Orange.....	30	30	4,990
	Beaumont.....	34	34	4,994
	Lake Charles.....	40	40	4,979
	Mississippi River			
	New Orleans.....	40	40	4,777
	Baton Rouge.....	40	40	4,894
	Gulfport.....	30	30	4,765
	Pascagoula.....	38	38	4,758
	Mobile.....	40	40	4,748
	Pensacola.....	33	33	4,721
	Panama City.....	32	32	4,705
	Port St. Joe.....	35	35	4,701
	Tampa Bay Area			
	Tampa.....	44	34	4,594
	Alafia River.....	30	30	4,593
	Big Bend.....	35		4,591
	Port Manatee.....	40	35	4,586
	Weedon Island.....	32		4,589

See footnotes at end of table.

TABLE A-1. - Port and channel information - Continued

Siting region	Port	Authorized project depth, feet	Controlling or reported depth, feet	Sailing distance from DOMES Site B, nautical miles ¹
Hawaii.....	Honolulu.....	35	35	1,244
	Kahului.....	35	35	1,195
	Kawaihae.....	35	35	1,150
	Hilo.....	35	35	1,085
	Nawiliwili.....	35	35	1,285
	Port Allen.....	35	35	1,275

¹DOMES Site B (110° 42' N latitude and 138° 24' W longitude) is near the center of the manganese nodule area of greatest commercial interest.

²Many waterways in Puget Sound are naturally deep (greater than 20 m [60 feet] within 600 m [2,000 feet] of shore); therefore, dredging is usually not required. Port depths are not indicative of available water depths.

³To Vancouver (Nautical Mile 92).

APPENDIX B. GEOLOGIC, SOILS, AND CLIMATIC DATA

For evaluating the suitability of potential waste disposal sites and expected environmental effects, geology and climate are important factors. This appendix includes supplementary information on the general geologic characteristics of the five representative sites, the average monthly water balance for the five sites, and the annual water balance for their corresponding regions. Selected soils information is provided within the descriptions of site geology.

Pacific Northwest Site Geology

The geology of the Pacific Northwest siting region is predominately a mix of volcanic rocks, marine sediments, and glacial and glaciomarine deposits. The volcanic rocks are associated with the principal peaks of the Cascade Range and the Olympic Mountains near the perimeter of the siting region and/or above 2,500 feet MSL. The glacial deposits of the region, of which the Cherry Point, Washington site geology is representative, are confined to the Puget Trough of Washington State because of the extent of previous glaciation.

Geologically the Cherry Point site consists of unconsolidated sediments, primarily Bellingham (and Bellingham glaciomarine) drift, overlain in the central part of the site around Lake Terrell and in the northwestern part of the site near Point Whitehorn by sand and gravel. There are small localized peat deposits near Lake Terrell and Mountain View. The unconsolidated sediments in the vicinity of the site have a thickness greater than 120 m (400 feet) (134). Beneath the glacial deposits of the Fraser Glaciation--the Bellingham drift, Deming sand and Kulshan drift of the Everson Interstade and the Vashon till and Esperance sand member of the Vashon drift from the Vashon Stade--are the Huntingdon formation, which is mostly sandstone and shale and the Chuckanut formation which is sandstone, conglomerate and shale (with coal in some places) (91). This sequence is shown in figure B-1.

Parts of the Bellingham drift consist of unsorted, pebbly, sandy silt and pebbly clay and have low permeability. Site-specific studies would be required to confirm suitability for waste disposal because of the variability of these glacial deposits.

Although the site is not representative geologically of the entire siting region, it does represent conditions that would be encountered in seeking a site relatively near the coast, with favorable terrain, with lower net precipitation than is typical and not within Federally protected lands.

Southern California Site Geology

The geology of the Southern California siting region is highly variable, but the Casmalia site is representative of the better conditions available in Santa Barbara and San Luis Obispo Counties. Typically sites underlain by old clayey sediments or crystalline rocks such as granite are favored for waste disposal. Marine sediments including shales are more likely north of Los Angeles, while granite rocks can be found within 100 km (50 miles) of the coast between San Diego and Los Angeles. The most favorable terrain in Southern California does not correspond with favorable geology and is also largely developed. Selecting preferred geology in this region will typically lead to siting in low hills and similar moderate terrain.

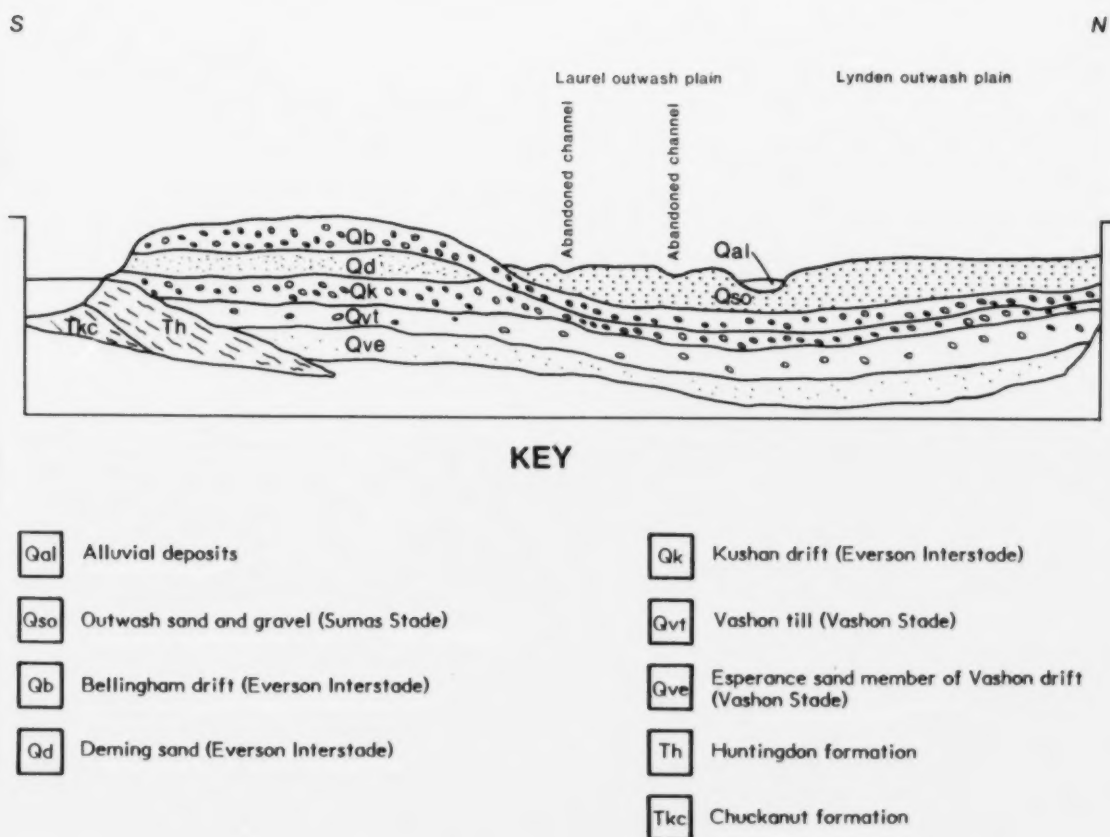
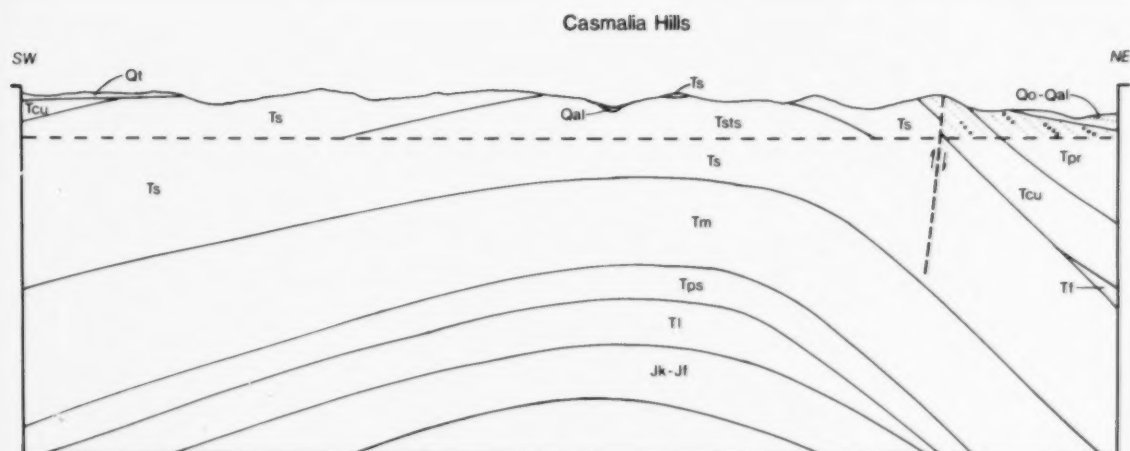


FIGURE B-1. - Diagrammatic geologic cross section for western Whatcom County, Washington.

The complicated geology of the region is largely a consequence of displacement caused by faults. The result is that a number of geologic units are found on the Casmalia site. All but one originated in either the Tertiary or Quaternary Period of the Cenozoic Era; the exception is a small pocket of Mesozoic ultrabasic intrusive rocks at the middle of the site's western boundary. Of the 11 units present, the dominant one is the Upper Miocene marine sediments, which run diagonally northeast to southwest through the middle of the site and underlie the Casmalia Hills. The Sisquoc formation is found here, and it is composed of massive diatomaceous mudstone, porcelainous claystone beds, and some porcelainous shale. North of this and running roughly parallel to it are bands of different geologic units: Middle and/or Lower Pliocene marine sediments (containing the Foxen mudstone formation with mudstone, siltstone and sandstone), Upper Pliocene marine sediments (containing Careaga sandstone and sand), Pleistocene nonmarine sediments (containing Orcutt sand), and Quaternary nonmarine stream terrace deposits in the northeast corner of the site. In this sequence the oldest unit is the Upper Miocene marine sediments in the center of the site; moving toward the northeast, the bands become progressively younger. A diagrammatic geologic cross section is given in figure B-2.

Parallel to and south of Casmalia Hills are the Middle Miocene marine sediments with the Monterey shale formation composed of porcelainous shale, laminated diatomite, and diatomaceous shale. Alluvium deposits are found along the river that cuts through



KEY

Qal Alluvium	Ts Sisquoc formation Diatomaceous strata
Qt Terrace deposits younger than Orcutt sand	Tsts Sisquoc formation Todos Santos claystone member
Qo Orcutt sand	Tm Monterey shale Upper member
Tpr Paso Robles formation	Tps Point Sal formation
Tcu Careaga sandstone Undifferentiated Careaga sandstone	Tl Lospe formation Undifferentiated Lospe formation
Tf Foxen mudstone	Jk Knoxville formation
	Jf Undifferentiated igneous rocks of Franciscan formation

FIGURE B-2. - Geologic cross section near Casmalia, California.

Shuman Canyon. To the south of the canyon are Pleistocene nonmarine sediments of Orcutt sand, and in the site's southwest corner are dune sands.

The Casmalia Class I disposal site is located on a terrace with a slope of less than 10% in the Casmalia Hills. The Sisquoc formation, which is part of the Upper Miocene marine sediment unit, underlies Casmalia Hills, including the disposal site, and its dominant constituents are claystone and diatomaceous shale that has textural homogeneity (207).

Three faults or portions of faults run through the site. In the site's northwest corner a fault separates the Middle Miocene and the Upper Miocene marine units. A short fault at about the middle of the eastern boundary separates the Upper Miocene

marine and the Pleistocene nonmarine units. Another fault runs from about the middle of the western boundary between Casmalia and Shuman Canyons. These faults are pre-Quaternary (older than 2 million years) or faults without recognized Quaternary displacement; they have no apparent signs of activity during the Quaternary period and are probably "dead".

The closest Quaternary fault to the site is about 5 km (3 miles) from the site's eastern boundary. This is a short fault without historic displacement. The closest major faults are the Santa Ynez, 40 km (25 miles) to the southeast; the Ozena, 50 km (31 miles) to the west; and the Rinconada, 42 km (26 miles) to the north. These are major Quaternary faults that have shown displacement during that period, but not in historic record (approximately within the last 200 years). The nearest major fault with historic displacement is the Big Pine fault, about 72 km (45 miles) to the east, which showed displacement in 1852. The San Andreas, which separates the North American tectonic plate from the Pacific plate, runs roughly parallel to the coast and its nearest point to the site is 88 km (55 miles) west. Offshore, about 24 km (15 miles) northwest of Point Sal, is the Hosgri fault zone.

The soils in the Casmalia Hills are mostly mollisols with alfisols located on the northern and southern portions of the site. Entisols are located in the southwest corner of the site. The surface of mollisols is thick, dark, and dominated by divalent cations. Granular structures in the soil keep it from hardening, even when dry. With sufficient rainfall or irrigation, they are excellent for agriculture. Alfisols have gray-brown surface horizons, a medium to high base status, and an illuvial horizon with silicate clays. These soils are dry, but with irrigation they are also very good for agriculture. Sandy entisols are in the southwest portion of the site. Part of the area contains sand dunes, and in places the sand has begun to develop into a mineral entisol soil. The soil is recent with deep regolith and virtually no soil horizons.

The Casmalia Hills are composed of consolidated marine sedimentary rocks that are essentially not water-bearing. These dense and compact rocks from the Sisquoc formation, the Monterey shale, and Foxen mudstone, allow virtually no percolation or storage. Recharge rarely occurs due to the rocks' impermeability and low rainfall. A few wells have been drilled in these consolidated rocks, but insufficient quantities of water were found for domestic and stock uses (465, 207). However, most of these formations contain fissures, joints, and fractures induced by folding and faulting, and it is conceivable that in specific areas they may transmit water to adjacent unconsolidated deposits.

Most of the other formations on the site are unconsolidated rocks. The Orcutt sand formation accounts for most of the area within the site with unconsolidated rocks, followed by river and stream terrace deposits, dune sand, and alluvium. The Orcutt formation supplies appreciable quantities of water only beneath the Orcutt upland, where the lower member is a principal water-producing deposit. River and stream terrace deposits transmit large seepage losses vertically downward whenever there is any runoff. Their permeability increases greatly upstream because the sediments are generally coarser. The dune sands transmit water; however, no tests have been made on their permeability (465). Alluvium's lower members rapidly transmit water and they are often saturated and readily yield water. Upper members and downstream deposits are often fine grained and are capable of transmitting water only in small or negligible quantities.

Gulf Coast Site Geology

The Gulf Coast has a large east-west variation in geology because of the lateral extent of the region. The region is underlain by thick (3,000 - 5,000 m +) platform deposits over Paleozoic basement rocks. The origin of these deposits causes variations from the fluviially deposited Pleistocene clays and muds in Southern Texas to the limestone areas of Gulf Coast Florida. Seismicity of the region is low. Salt domes are also found from the Houston to New Orleans within the study area. The Corpus Christi site represents only the geology of the drier parts of the study area. Where wetlands are more common or salt structures or limestone are prevalent, geologic suitability for waste disposal would be substantially different.

The geology of the site (figure B-3) consists of Pleistocene fluvial-deltaic deposits of the Beaumont formation. Much of the site is covered with interdistributary muds, including bay, floodbasin, and abandoned channel facies. These low-permeability clays, ranging from 10^{-6} - 10^{-3} cm/sec (10^{-3} -10 gal/sq ft/day), exhibit good suitability for waste disposal (463). They also have high water-holding capacity, high compressibility, high to very high shrink-swell potential, poor drainage, low shear strength, high plasticity, low foundation strength and high corrosion potential (186). About one-third of the site is covered with distributary and fluvial sands and silts. These deposits are shallow aquifers that are recharged locally. Their permeability ranges from 10^{-1} - 10^{-2} cm/sec (10^3 - 10^6 gal/sq ft/day) (463). Along Oso Creek are deposits of Modern and Holocene alluvium. Several low areas that are susceptible to early flooding and ponding occur on the site.

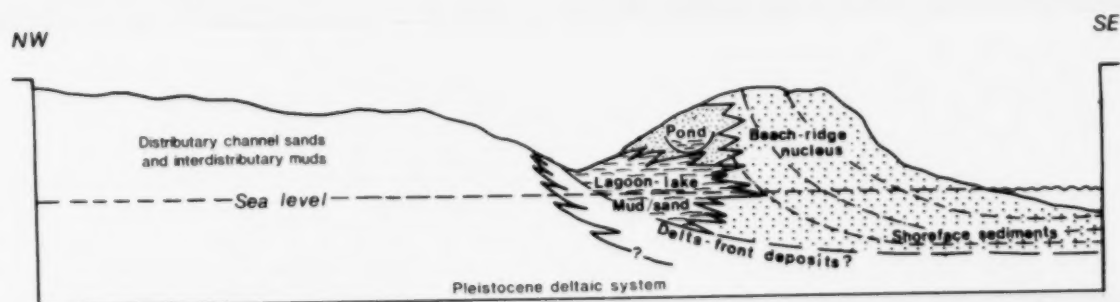


FIGURE B-3. - Diagrammatic Pleistocene geologic cross section near Corpus Christi, Texas.

Hawaii Sites Geology

The Hawaii Islands are almost wholly volcanic--mainly basaltic rocks. The vast majority of the volcanic rocks are lava flows. Sedimentary rocks form only a narrow fringe around the edges of parts of some (principally the older) islands. Where the sediments have accumulated they act as a caprock retarding the seaward movement of fresh water from underlying more permeable basaltic aquifers. Sedimentary rocks are not commonly found on the island of Hawaii, where the two representative sites are found.

Lava flows are of two types--pahoehoe and aa--and both are formed on the Hilo site. Pahoehoe has a smooth but often wrinkled surface that is formed as the lava continues to flow under a cooled and hardened surface. Pahoehoe often changes to aa as it flows downhill. Aa has a rough surface with jagged basalt fragments. Both types of lava contain many small holes formed by gas bubbles.

The soils on the Hilo site are primarily Papai, an extremely stony muck formed over fragmental aa. It is a thin, well-drained, organic soil with rapid permeability, slow runoff, and slight erosion hazard. Papai soils are interspersed with exposed pahoehoe soils, which are also well-drained with slight erosion hazard. Near the center of the site is an area covered with Keaukaha, a thin, extremely rocky muck with characteristics similar to Papai with the exceptions that it is formed over pahoehoe, not aa, and its pH is generally less than that of Papai. The depth of both soils to the underlying lava is less than .5 m (1 foot).

The Papai and Keaukaha soils are rated as having moderate limitations for development construction and pahoehoe is rated as having severe limitations. (Within the South Hilo area there are no areas with slight limitations; a rating of moderate limitation is the best rating.) The Papai and Keaukaha soils are grouped in Soil Conservation Service Capability Class Vlls, based on limitations that generally makes them unsuitable for agricultural cultivation. However, these soils can be used to produce macadamia orchards. The pahoehoe is grouped in Class VIII, the most limiting capability class. In general, the soils and geologic structures of the site are not well suited for development, construction, or agricultural uses, although the same can be said for much of the land on the island of Hawaii.

On the Kohala (Kawaihae) site, lava flows from the Kohala volcano are responsible for the geology of the northern section. The Kohala volcano is the oldest on the island and was extinct before all others. There have been no lava flows in recorded time. The Pololu volcanic series, which was lava flows from this volcano, underlies most of the northern third of the site. Two fingers of the more recent Hawi volcanic series enter into the site at the northern boundary. The Pololu series underwent great erosional unconformity, although the resultant landscape is not nearly as rugged as it is on the eastern slope of the mountain. The Pololu series is composed of thin-bedded primitive olivine basalts with porphyries at the top in most places. The Hawi series is composed chiefly of oligoclase andesites and a few soda trachytes. The underlying lava flows within a mile of the coast are pahoehoe, while the rest of this section is underlain by aa.

The geologic formation of the southern two-thirds of the site consists of the Hamakua volcanic series from the Mauna Kea volcano, capped by Pahala ash. It is primarily olivine basalts with picrite basalts carrying olivine and augite phenocrysts. Mauna Kea has not erupted in historic times, but it is younger than the Kohala volcano and its flows cover some of those from Kohala throughout part of the site. The lava in this section is pahoehoe.

Where soils have developed, the Kawaihae series is the most prevalent. The Kawaihae series covers most of the site except for a ribbon of the Puu Pa soil series, which lies diagonally across the northeast portion of the site with soils from the Waimea series in the extreme northeast corner of the site. The Kawaihae soil series includes somewhat excessively drained, extremely stony soils that formed in volcanic, in this case Pahala, ash. Its permeability is moderate, runoff is medium, and erosion hazard is moderate. The depth of the soil ranges from .5 to 1 m (1.5 to 3.5 feet) and there is a hard bedrock of pahoehoe beneath the soil. The thin surface of the soil is fine sandy

loam below which is stony silt loam, and stony loam. The surface layer is neutral while the subsoil is neutral to mildly alkaline.

The Puu Pa soil is well-drained, extremely stony, very fine sandy loam that has formed on volcanic ash. It is similar to the Kawaihae soils except that it is found at higher elevations, is formed over aa, is medium to slightly acidic at the surface, and is a sandy loam throughout its profile. The depth to the aa bedrock ranges from .5 to 1 m (1.5 to 3 feet). Its permeability is moderately rapid, runoff is medium, and erosion hazard is moderate.

The Waimae soil covers only a small portion of the northeast corner of the site. It is a well-drained, very fine, sandy loam formed on volcanic ash. Its permeability is moderately rapid, runoff is slow, and erosion hazard is slight.

Throughout the site there are bare patches of basalt. Where soils have developed, most of them are grouped in Capability Class VII, which is the second worst rating, and they are generally unsuitable for agricultural purposes. The Kawaihae soil north of the Makeahua and Palihae Gulches, in the northern section, is grouped in Capability Class VI, which is also poorly suited for agriculture. The soils are more suited for pasture or range land. They support piligrass, ilima, fingergrass, bermuda grass, cactus and, along the coastal flats, kiawe trees. Most of the area is open scrub grassland. About three-fourths of the forage is produced during the rainy winter months, and in the dry summer the annuals die and the perennials are dormant. Much of the site is barren of vegetation.

Precipitation vs. Lake Evaporation Data

In order to characterize the five siting regions, one of the most important features that could be displayed graphically was the annual difference between precipitation and evaporation. Previous manganese nodule studies have discussed the water balance regarding evaporating liquid wastes and limiting leachate generation, but no comprehensive picture has been assembled across geographic areas. Rogers, Golden & Halpern, using available maps of precipitation for the period 1931-1960 (100) and lake evaporation for the period 1946-1955 (100) contoured the differences between the maps for the Pacific Northwest, Southern California, and Gulf of Mexico siting regions (figures B-4, B-6, and B-8). For Hawaii, adequate data to produce a map was only available for Hawaii County (176). The only available net evaporation map for Hawaii did not contour water surpluses, so for purposes of illustration we have shown annual rainfall minus 125 cm (50 inches) of precipitation--a typical evaporation value for water surplus areas--as dotted lines in figure B-10. Solid waste contours indicate the amount by which evaporation exceeds precipitation.

These values are generalized for all five siting regions. Specific measurements would have to be taken on-site. There is currently no available mapping that summarizes and extrapolates the available recording station data through the present.

Following each regional map are graphs (figures B-5, B-7, B-8, B-11, and B-12) of average month by month precipitation vs. evaporation for the representative site(s) shown on the regional map. For the continental U.S. sites, normal precipitation data for the period 1941-70 (261) and maps of average monthly pan evaporation data for 1931-60 (42) adjusted using appropriate pan coefficients (100) were used. For the Hawaii sites, precipitation and evaporation data developed by the Hawaii Division of Water and Land Development (155) were used to construct the graphs. The monthly data is important to understanding management of waste disposal at the sites. For example, sites such as

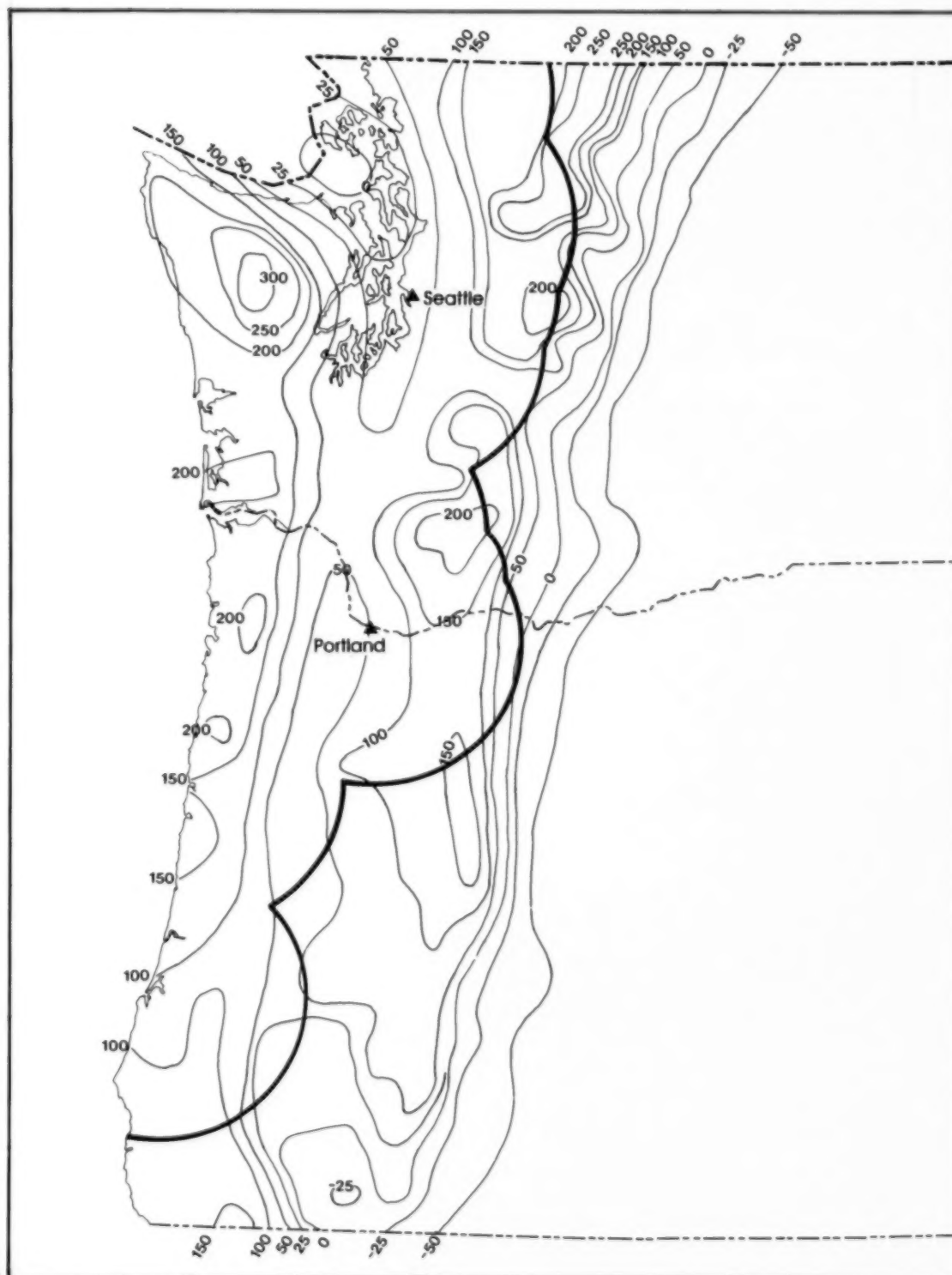


FIGURE B-4. - Precipitation minus lake evaporation in cm for the Pacific Northwest siting region.

Hilo for which precipitation exceed evaporation by a significant amount in every month would have a large amount of additional water to decant and treat, and wastes would be difficult to stabilize. However, sites with substantial excess evaporation in a few months (for example, Bellingham) could be expected to benefit from stabilization through evaporation of liquid wastes.

The illustrations present the data we have collected. Please note that the concept of wet and dry climate is relative; that is, a Gulf Coast site that is considered wet would be relatively "dry" in the context of wet climate areas of Hawaii, even though all sites with precipitation surpluses would require a method to dispose of the excess water.

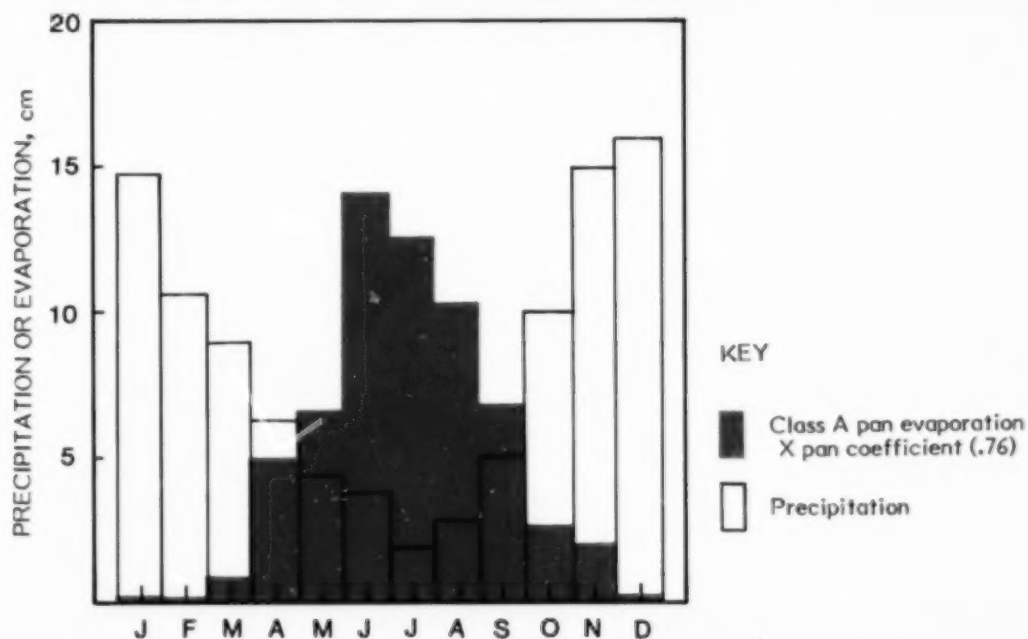


FIGURE B-5. - Monthly precipitation for Seattle and adjusted Class A pan evaporation for Bellingham, Washington.

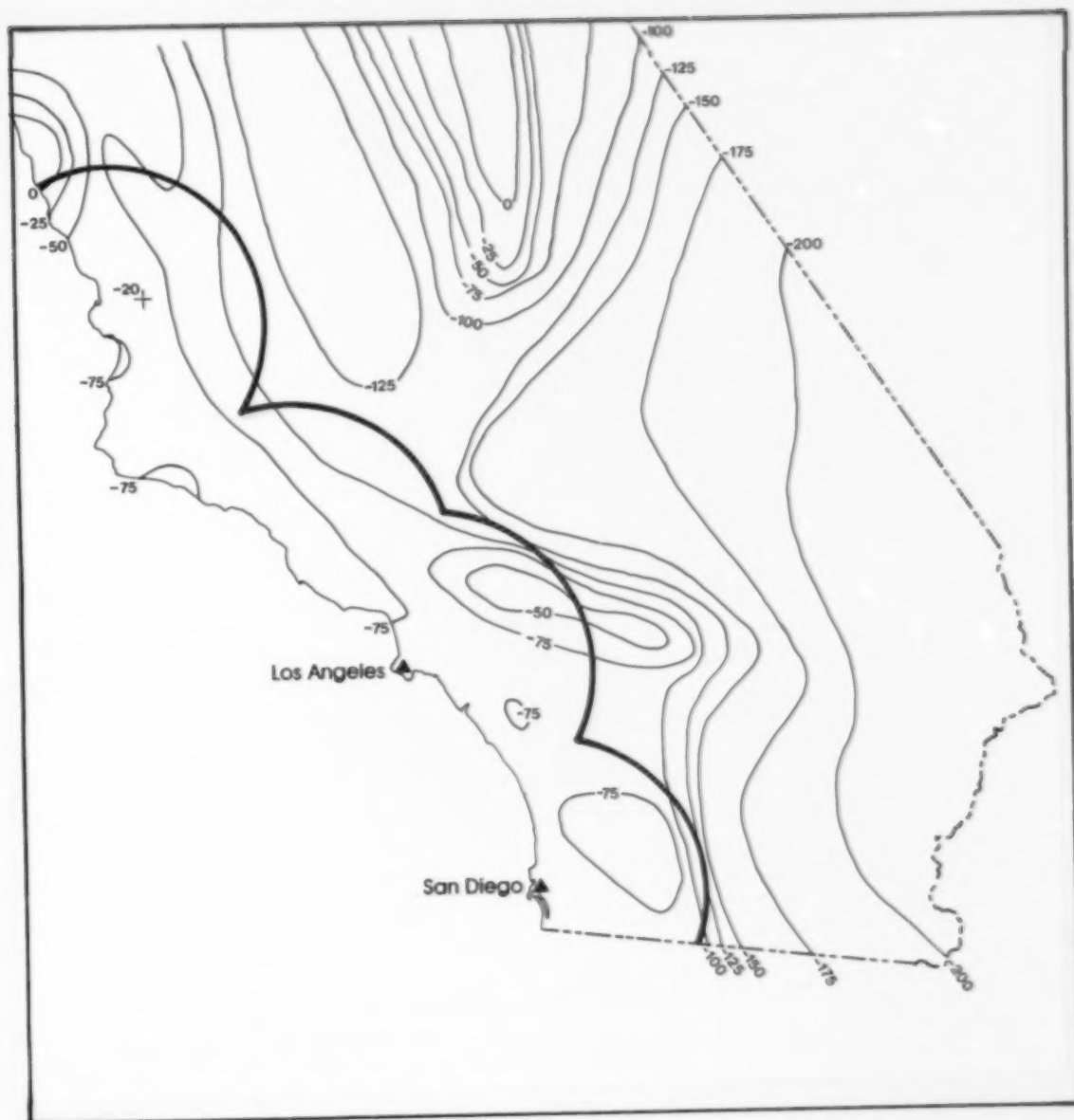


FIGURE B-6. - Precipitation minus lake evaporation in cm for the Southern California siting region.

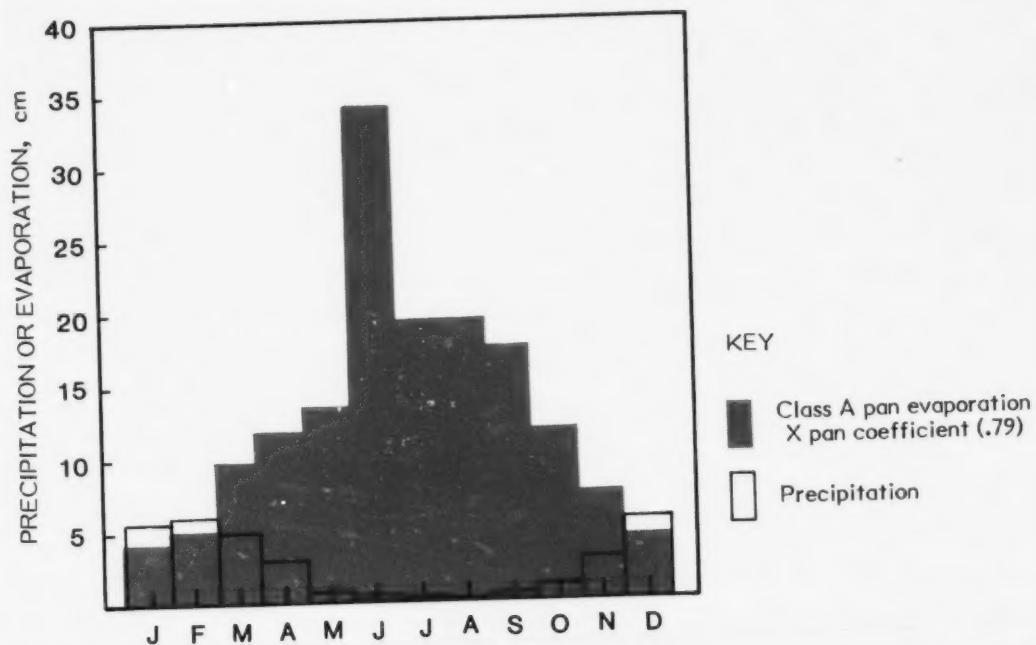


FIGURE B-7. - Monthly precipitation and adjusted Class A pan evaporation for Santa Maria, California.

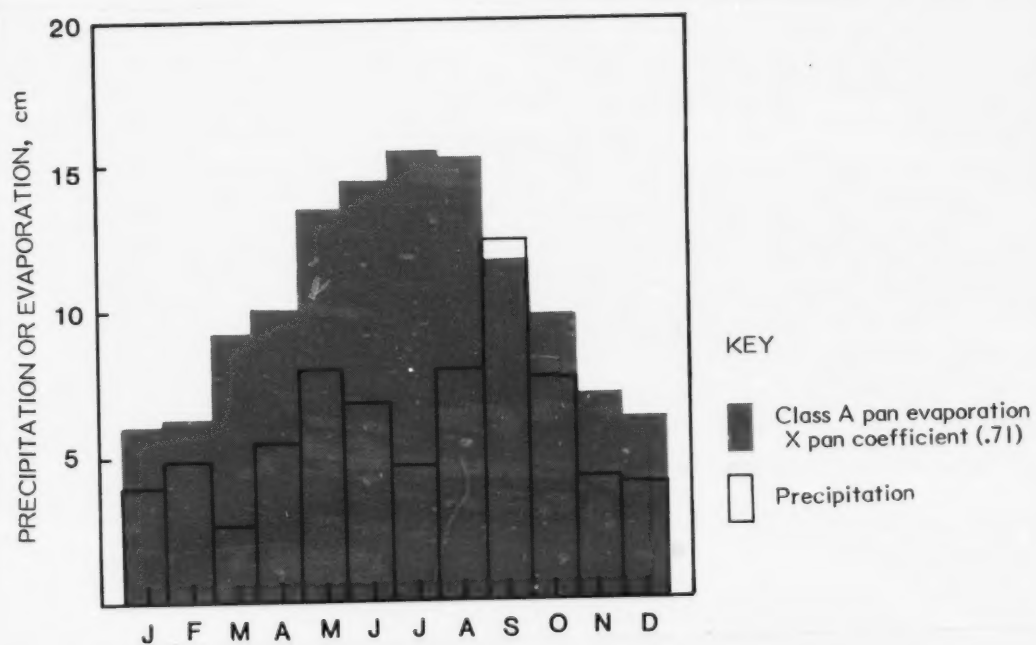


FIGURE B-8. - Monthly precipitation and adjusted Class A pan evaporation for Corpus Christi, Texas.

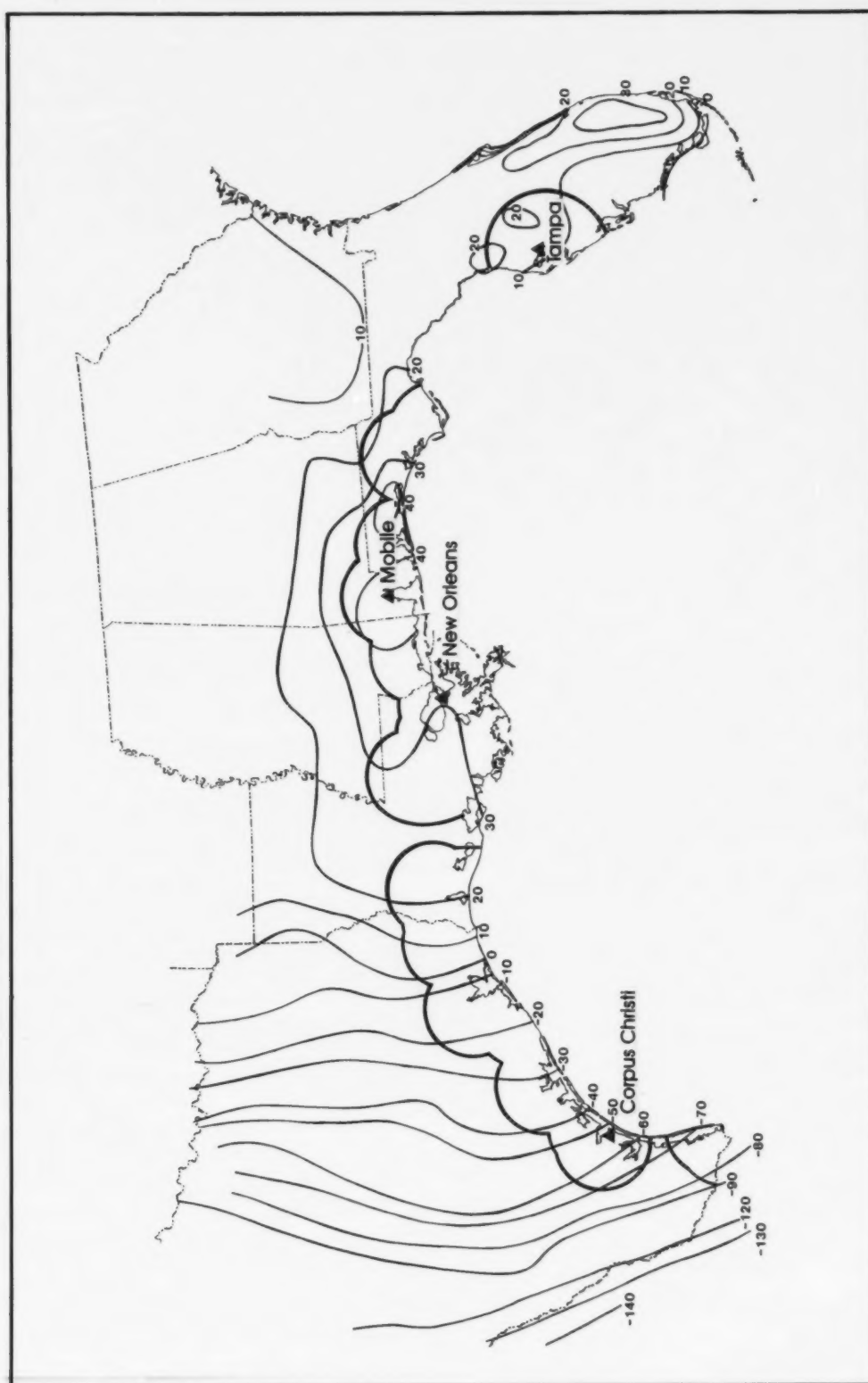


FIGURE B-9. - Precipitation minus evaporation in cm for the Gulf of Mexico siting region.

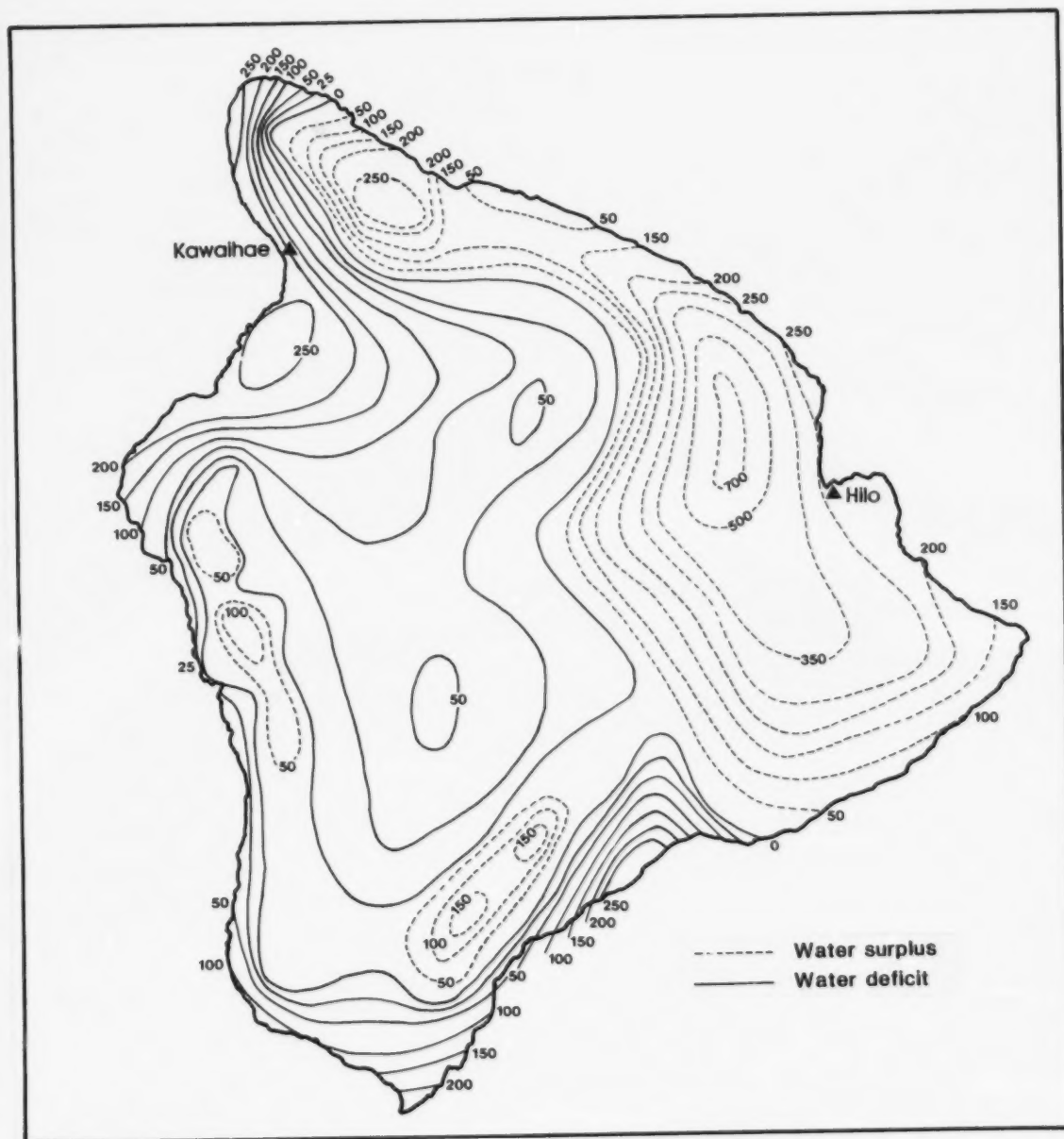


FIGURE B-10. - Precipitation minus evaporation in cm for Hawaii County.

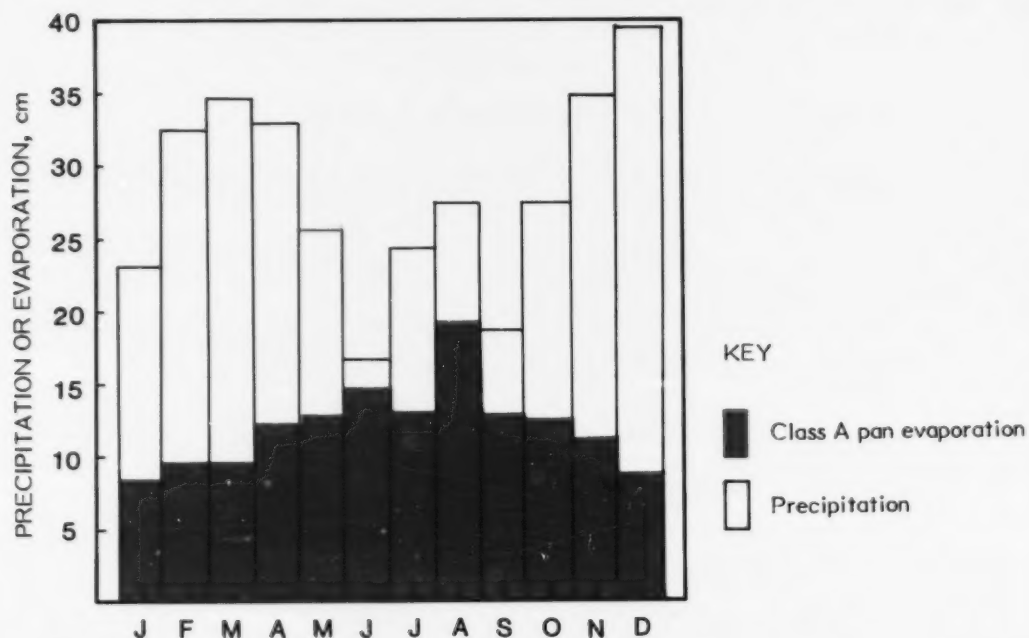


FIGURE B-11. - Monthly precipitation and Class A evaporation for Hilo, Hawaii.

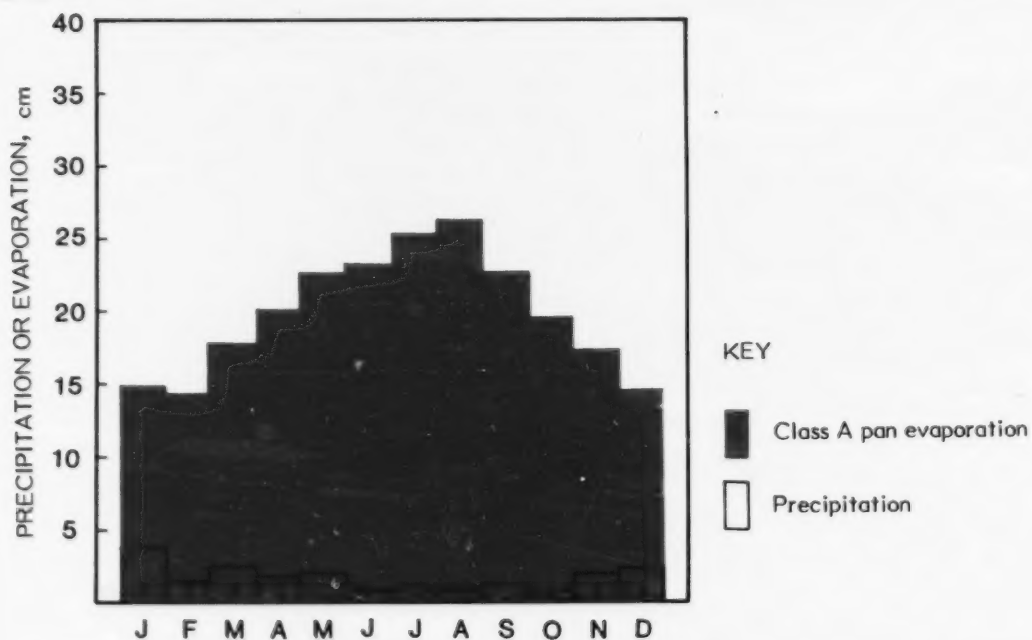


FIGURE B-12. - Monthly precipitation for Kawaihae and Class A pan evaporation for Hawi (Station 3), Hawaii.

APPENDIX C - SYNOPSIS OF ADDITIONAL RELEVANT REGULATIONS

Federal Regulations

The following Federal statutes were listed in the main text but were not described in detail. The applicability and relevance of these acts and related regulations would be determined on a case-by-case basis, and they would only be significant at certain sites.

Coastal Zone Management Act of 1972 (CZMA)

Because manganese nodule processing activities require ports, manganese nodule reject disposal sites may be located in a coastal area, and CZMA may apply. Enacted in response to increasing and competing demands on coastal zone lands and waters, CZMA initiated a Federal grant assistance program to help coastal States develop and administer CZM plans. If a State has an approved CZM program, any Federal agency action affecting the coastal zone must be consistent with the program, unless the Secretary of Commerce formally overrides the State objections. The States of California, Washington, and Hawaii have approved CZM programs, but Texas does not.

The applicability of CZMA to a particular waste disposal site will depend on the location of the coastal zone boundary. For instance California's coastal zone is quite narrow in most places (3,000 feet inland from the mean high tide line and narrower in developed urban areas), although designated "bulges" extend further inland in some places to protect estuarine, habitat, and recreational resources. Hawaii, on the other hand, has rather large areas that fall under the CZM program, so it is more likely that a waste disposal site would be located in the coastal zone in that State. Washington's coastal zone includes coastal counties.

Any applicant for a Federal license or permit to conduct an activity affecting the coastal zone must certify consistency with the program, after which the State must notify the applicable Federal agency of its concurrence with or objection to the certification. This provision gives local, areawide, and regional agencies, as well as States, direct input into the permit process.

Another provision in CZMA directs that the State program set "broad guidelines on priorities of uses in particular areas, including specifically those uses of lowest priority." Because these priority uses may work to the advantage or disadvantage of a permit applicant, serving to facilitate or to deter the proposed development, they warrant careful examination. For example, a port facility, as a waterfront-related use, might be considered a priority use, whereas a processing plant or disposal facility might have low priority under a CZM plan and may be discouraged or prohibited.

Fish and Wildlife Coordination Act of 1958 (FWCA)

Under FWCA, Federal agencies that propose or authorize projects that affect waterbodies or that issue licenses or permits affecting waterbodies must consult with the U.S. Fish and Wildlife Service (FWS), except for the impoundment of small bodies of water (less than 10 acres) or the management and use of Federal lands.

While this statute would apply to port-related facilities, it probably would not be directly involved with onshore waste disposal unless the diversion, impoundment, or other alteration of a body of water were undertaken. The U.S. Army Corps of

Engineers (COE) dredge and fill permit applications are subject to this statute, as outlined in a 1967 Memorandum of Understanding. COE policy strongly discourages unnecessary alteration or destruction of wetlands and any proposed operations that will "unreasonably impair natural resources or the related environment."

Endangered Species Act of 1973 (ESA)

Enacted to protect and conserve endangered and threatened species and their critical habitats, ESA provides for the listing of species determined to be endangered or threatened and designation of their critical habitats. Federal agencies must ensure that "actions authorized, funded, or carried out by them do not jeopardize the continued existence of such endangered...and threatened species or result in the destruction or modification of (critical) habitat of such species...." In addition, ESA, through funding allocations, encourages States to enter into cooperative agreements with the Federal government to achieve the goals of ESA. California and Washington have entered into cooperative agreements with FWS, while Hawaii is actively working toward applying for an agreement and Texas has expressed some interest in an agreement.

The construction of a manganese nodule reject disposal facility would necessitate consideration of the effects of the facility on endangered and threatened species and their critical habitats. This consideration would be carried out through agency consultation during various permitting processes.

National Migratory Bird Treaty Act of 1918 (NMBTA)

NMBTA makes unlawful, with certain exceptions, the taking, killing, or possession of migratory birds and provides for enforcement of its provisions. NMBTA has been used in court cases where hazardous conditions have resulted in a "taking" of migratory birds. Waste disposal ponds may attract wildlife, particularly waterfowl, which may ingest harmful substances and become poisoned and perhaps die. Another concern by wildlife officials is that birds containing toxic chemicals will be ingested by humans and cause adverse health effects.

National Historic Preservation Act of 1966 (NHPA) and the Preservation of Historical and Archaeological Data Act of 1974 (PHADA)

NHPA set up a national register of places of historic, cultural, and archaeological significance, established a grant program to States to prepare comprehensive programs and plans, and established an Advisory Council on Historic Preservation. Under NHPA, Federal licensing agencies must consider the effect of proposed activities on registered historic sites and sites eligible for inclusion in the national register.

PHADA provides for "the preservation of historical and archaeological data... which might otherwise be irreparably lost or destroyed as a result of...alteration of any Federally licensed activity or program," by directing that significant data be recovered and preserved. Survey and recovery of such data could cause significant delay of a project.

The Wilderness Act of 1964

The nation's first wilderness area was established in Gila National Forest in 1924 by means of the district forester utilizing his administrative authority. This marked the beginning of the National Wilderness Preservation System (NWPS). The concepts of wilderness were formalized 40 years later with the Wilderness Act, which gave

Congress sole authority to add to the NWPS in order "to secure for the American people of present and future generations the benefits of an enduring resource of wilderness." According to the Wilderness Act, wilderness is "an area where the earth and its community of life are untrammelled by man, where man himself is a visitor who does not remain."

Wilderness areas are found in national forests, national parks, national wildlife refuges, and lands managed by the Bureau of Land Management. The Forest Service, under its Roadless Area Review and Evaluation (RARE II) program, has reviewed lands under its jurisdiction and identified wilderness areas, nonwilderness areas, and areas for further planning. The last-named may be designated as wilderness in future plans.

Wild and Scenic Rivers Act of 1968 (WSRA)

WSRA provides for the designation of selected segments of rivers having "outstandingly remarkable scenic, recreational, geologic, fish and wildlife, historic, cultural, or other similar values" to be preserved in free-flowing condition and their immediate environs "protected for the benefit and enjoyment of present and future generations." Another stated goal of WSRA is "to protect water quality and fulfill other vital national conservation purposes."

WSRA sets up the NWSRS, designates initial components of NWSRS, and prescribes methods and standards for adding additional components. The three designations under NWSRS are wild river areas, scenic river areas, and recreational river areas.

WSRA directs all Federal agencies involved in planning for the development of water and related land resources to consider potential national wild, scenic, and recreational river areas. If any water resources project-related action taken by an agency will undermine the values for which the river was established in the system, the agency must advise the Secretary of the Interior or the Secretary of Agriculture in writing at least 60 days in advance and report the contemplated action to Congress.

State Regulations

Within the States having representative sites, there are State regulations that only apply for certain sites and under certain conditions. These are briefly described below.

Washington

The State of Washington's environmental policy rests on the State Environmental Policy Act of 1971 (SEPA), which is basically modeled after NEPA at the Federal level. All branches of the State government, including State agencies, municipal and public corporations, and counties must include a detailed environmental impact statement (EIS) in recommendations or reports on proposals for legislation and other major actions having significant effects on environmental quality. The issuance of various State permits for the manganese nodule reject disposal facility will certainly require a State EIS. The Washington State Department of Ecology (WDOE), the agency responsible for implementing SEPA, has issued regulations governing the preparation of an EIS. The actual preparation of the EIS is the responsibility of the "lead agency," or the agency having primary regulatory responsibility for the project, but it may be prepared by the

permit applicant in accordance with WDOE regulations and lead agency guidelines. Input to the EIS is solicited from appropriate Federal agencies, affected local agencies and political subdivisions, any city or county in which there is a likelihood of adverse environmental effects, and the general public. If an adequate EIS has been prepared under NEPA, it may be used in lieu of the final EIS under SEPA.

Under the Environmental Coordination Procedures Act (ECPA) of 1973, a permit applicant for a project requiring several permits may submit a master application to WDOE, which notifies and solicits comments from other State agencies having an interest in the proposed project. The notified agencies can respond with information regarding what permit programs may fall under their jurisdiction. WDOE then sends the relevant forms to the applicant for completion. Public notice must be given by the applicant and a determination must be made as to whether or not an EIS is required under SEPA. When several permits are involved, an EIS will certainly be required. After a public hearing, the participating agencies must submit their final decisions to WDOE. Under ECPA, these agency decisions will be reviewed by the Pollution Control Hearings Board if a request is made for an appeal of WDOE's decision. ECPA also provides for judicial review of Board decisions.

Coastal Zone Management

The Washington Shoreline Management Act (WSMA) of 1971 and its concomitant regulations set up a statewide CZM program. The regulations provide for local governments to prepare local shoreline master programs. The purposes of WSMA include fostering reasonable and appropriate uses and promoting and enhancing the public interest. Special attention is given to "shorelines of state significance." Development proposed for the coastal zone must be consistent with the WDOE shoreline permit regulations and the approved local master program. For "substantial development," which certainly would apply to manganese nodule-related facilities, shoreline-dependent users have the best prospects for obtaining a permit. The WDOE guidelines make a distinction between water-dependent uses, water-oriented uses, and non-water-oriented uses, and they give priority to uses dependent on the shoreline or to uses that cannot be economically operated inland. It is unlikely that a waste disposal facility would be permitted in shoreline areas for this reason and because solid waste disposal is a discouraged use.

The proposed WDOE Dangerous Waste Regulations state that, for areas under jurisdiction of the WSMA, no dangerous waste disposal facility will be located in wetlands, or in areas classified as natural, conservancy, rural, or residential.

The State CZM program is a Federally approved program, and as such is subject to the Federal consistency provision. Its permit program also falls under the State ECPA's master application procedure and SEPA.

Other Regulatory Areas

If State lands are involved in a development proposal, a lease must be obtained from the Department of Natural Resources.

Fugitive dust and particulates are regulated by WDOE standards for maximum permissible emissions of particulate material under the authority of the Washington Clean Air Act of 1967. Reasonable precautions for the prevention of pollution must be taken.

California

The statutory basis for environmental protection in California rests on the California Environmental Quality Act (CEQA), modeled after NEPA. CEQA stipulates that any project that may have a significant effect on the environment necessitates the preparation of an environmental impact report (EIR) for consideration by public agencies responsible for granting approval of the project. It is most likely that all manganese nodule process-related facilities, including waste disposal, would be considered as a single project for the purposes of preparation of an EIR. The lead agency is responsible for preparing the EIR. The lead agency could be a city, county, port authority, or the State Lands Commission. State and Federal agencies are notified and consulted for relevant information prior to preparation of the draft report. This consultation may be handled through the State and areawide clearinghouse systems. Public notice is made and comments solicited on the draft before the final EIR is prepared. The EIR must be considered in deciding whether or not to approve the project. An appeals procedure is in place for anyone who wishes to challenge the decision of the lead agency, or a responsible agency that objects may choose to prepare a subsequent EIR.

In order to speed up the environmental review process, the California legislature amended CEQA with Assembly Bill 884 in 1977. AB 884 sets a standard timetable for environmental approvals applicable to any State, regional, or local agency that is empowered to approve or disapprove a development project, and it also requires these State agencies to compile detailed lists of information and criteria for determining completeness of applications. It advises local agencies to formulate similar lists and criteria.

If an EIS is also being prepared under NEPA, the lead agency is required to consult with the agency preparing the EIS to see if a combined document can be produced.

In the case of a large capital project such as a manganese nodule processing plant and related facilities, preparation of a "staged EIR" may be considered in order to speed up processing. The initial EIR discusses general impacts of the project, and more detailed information is provided in supplements as approval of various project phases is required.

Coastal Zone Management

The California Coastal Act (CCA) of 1976 implements the California State Coastal Plan, which is a Federally approved plan under CZMA. The agencies responsible for conformity of coastal development with the Plan and for issuing coastal development permits are six Regional Commissions and a State Coastal Commission. By means of a sunset provision, the Regional Commissions are turning over their responsibilities to local governments, which are required under the CCA to develop Local Coastal Plans. After June 30, 1981, the Regional Commissions terminate and jurisdiction for localities that have not developed Local Coastal Plans will revert to the State Coastal Commission. The Coastal Commissions have review authority over Federal agency activities in the coastal zone, in accordance with CZMA, in order to determine whether or not those activities are consistent with the State Coastal Plan and CCA policies.

For proposed development at ports having a master plan that has been certified by the State Coastal Commission as being in conformance with CCA, the applicant need only comply with the provisions of the master plan. If the proposed development does

not conform with the plan, the master plan can be amended and the amendment certified by the State Coastal Commission.

CCA gives priority to coastal-dependent development over other types of development on the coast. In accordance with this policy, waste storage areas, other than temporary storage, would probably have to be located away from the waterfront.

Other Regulatory Areas

If any of the manganese nodule reject disposal facilities, including waste slurry pipeline rights-of-way, were to be located on State lands, they would be subject to the jurisdiction of the State Lands Commission (SLC). An application for Permit or Lease of State Lands must be submitted to SLC for review by a Land Agent, who would consult with SLC's Boundary Unit and Environmental Unit. In the case of manganese nodule processing and related facilities, SLC might serve as the lead agency or share the lead agency role with the local port authority. Dredging and filling on State lands would require a special permit from the State and would have to be carried out in conformance with approved dredge criteria promulgated by the SWRCB. Any dredging, diking, or filling activity that will degrade State-owned wetlands must be mitigated by acquisition or opening of areas of equal or greater biological productivity.

Air pollutants from the waste disposal facility would consist of fugitive dust and other particulates. On the State level, such pollutants are regulated by the California Air Resources Board or by the appropriate Regional Air Quality Management District. The role of the Board is to propose model rules and assist in rulemaking at the district level.

Texas

The State of Texas does not have an environmental policy act that requires an EIS for major projects having significant effects on the environment, nor does it have a coordinated, consolidated permit program for such projects. However, an EIS may be required by a particular agency, such as the Department of Water Resources (DWR) under the State Water Quality Rules.

Coastal Zone Management

Texas does not have an approved coastal zone management plan under the Federal CZMA. Land use controls in coastal areas are at the local level.

Other Regulatory Areas

The State owns all submerged lands along the Texas coast as well as some other areas designated as park lands. In the unlikely event that any of this land would be needed for manganese nodule related facilities, the General Lands Office would consider leasing or selling the land for "uses of benefit to the citizens of the state."

Air pollution from the waste disposal site, such as particulates and fugitive dust, would fall under the jurisdiction of the Texas Air Control Board, which regulates ambient air quality under the Texas Clean Air Act.

Construction in floodplains would fall under the jurisdiction of the Texas Water Development Board.

Activities affecting State archaeological landmarks are regulated under the Texas Antiquities Code. Permits for activities such as excavation or destruction of these landmarks are issued by the Texas Antiquities Committee.

Hawaii

The Hawaii Department of Health (DOH) is the primary environmental regulatory agency in Hawaii. Regulations related to environmental quality generally fall under the Hawaii Environmental Quality Law (EQL), which includes parts dealing with air pollution, water pollution, noise pollution, and solid waste pollution. Under EQL, DOH "shall consider the environmental impact of the proposed action, any adverse environmental effects which cannot be avoided should the action be implemented, the alternatives to the proposed action, the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented, and any other factors which the director may by rule prescribe." Thus DOH is authorized to perform an analysis analogous to the Federal EIS under NEPA.

Coastal Zone Management

The Hawaii CZM program, approved under the Federal CZMA, is administered at the State level by DPED. Under this program, manganese nodule-related activities are considered to be Uses of Regional Benefit, and as such are accommodated in the program. The State has control over 96% of its land by means of regulatory and acquisition powers in conservation, agricultural, and rural areas and by means of reclassification of uses in urban districts.

At the county level within the coastal zone, development in Special Management Areas is regulated by development permits under which CZM objectives and policies as well as specified standards and criteria must be met. Under some county regulations, an EIS may be required before a permit is issued.

Other Regulatory Areas

Fugitive dust from construction or operation of the disposal facility would be regulated by DOH under the air pollution section of EQL and the Air Pollution Regulations. Reasonable precautions, as approved by the DOH, must be taken to prevent particulate matter from becoming airborne. No visible emissions are allowed to occur past the property lines of the site, and specific ground level ambient air quality standards must be met at a point specified by the DOH.

Before construction can begin, State regulations require that a survey be made for possible archaeological sites. The survey is to be submitted to the Department of Land and Natural Resources.

APPENDIX D - PERSONS CONTACTED DURING THIS STUDY

The following contacts were made during the data-gathering trips to the siting areas and representative sites:

Southern California

Kieran Bergin	Los Angeles Department of Sanitation, Los Angeles, California
Cory Unfield Robert Waiwood	U.S. Bureau of Land Management, Regional Office, Bakersfield, California
Glen Barnhill Glenn Reins	Kern County Planning Department, Bakersfield, California
Martin Golden Debby Prestage	U.S. Bureau of Land Management, Pacific OCS Office, Los Angeles, California
Michael Kiado	California Department of Health Services, Hazardous Materials Management Section, Sacramento, California
Bruce Douglas Ellen Aronson	Southern California Association of Governments, Los Angeles, California
Paul Crawford Ronald DeCarli	San Luis Obispo County Planning Department, San Luis Obispo, California
Pat Beck	San Luis Obispo County CZM Representative, San Luis Obispo, California
Robert Baldridge	California Regional Water Quality Control Board, San Luis Obispo, California
Brad Seek	San Luis Obispo County Department of Health, San Luis Obispo, California

Hawaii

Raymond Jenkins (Consultant) Kent Keith	Hawaii Department of Planning and Economic Development, Honolulu, Hawaii
Ernest Kosaka	U.S. Fish and Wildlife Service, Honolulu, Hawaii
Tom Fake	U.S. National Park Service, Honolulu, Hawaii
Daniel Davis	U.S. Geological Survey

Gordon Soh	Hawaii Department of Land and Natural Resources Planning Department, Honolulu, Hawaii
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Carolyn Corn	Hawaii Department of Land and Natural Resources, Division of Forestry and Wildlife Endangered Flora Habitats, Honolulu, Hawaii
Wendall Kam Nathan Napoka	Hawaii Department of Land and Natural Resources, Division of Archaeology, Honolulu, Hawaii
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Dick Poirier	Hawaii Coastal Zone Management Program, Honolulu, Hawaii
Janie Patch James Woodruff	Hawaii Department of Planning and Economic Development, Division of Energy Programs, Honolulu, Hawaii
George Fujimoto	Hawaii Environmental Quality Board, Honolulu, Hawaii
Rodney Nakano Duane Kanuha	County of Hawaii, Department of Planning, Hilo, Hawaii
Patrick Watanda	U.S. Soil Conservation Service, Regional Office, Hilo, Hawaii
Quirimo Antonio, Jr.	County of Hawaii, Department of Water Supply, Hilo, Hawaii
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Texas Bureau of Economic Geology, Austin,
Texas

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Gerald Healy, Jr.,
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Louisiana Geological Survey, Baton Rouge,
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Louisiana Geological Survey, Baton Rouge,
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Louisiana Geological Survey, Baton Rouge,
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The following additional contacts were made:

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Dennis Peters	U.S. Fish and Wildlife Service, National Wetlands Inventory
Rebecca Debs	U.S. Department of Energy, Federal Regulatory Commission
Greg Dougherty	Florida Geological Survey, Mining Section
J. William Yon	Florida Geological Survey, Mining Section
John Outland	Florida Department of Environmental Regulation
Jean Coleman	U.S. Environmental Protection Agency, Mining Wastes Section, Atlanta Regional Office
M.A. Beg	Alabama Geological Survey
John Johnston	Louisiana Geological Survey
Holly Stokes	Texas Bureau of Mines
Ken Launius	Texas Railroad Commission, Office of Surface Mining and Reclamation
Dwight Sanders	California State Lands Commission
Tim Farley	California Department of Fish and Game
Dr. Ahmad Hassan	Los Angeles Department of Water Resources
J. Stevens	California Department of Mines Geology, Environmental Studies Section
John Burnett	California Department of Mines and Geology
Bob Middleton	U.S. Bureau of Land Management, Sacramento Regional Office
Bruce Conrad	U.S. Bureau of Land Management, Sacramento Regional Office
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John Byrne	U.S. Fish and Wildlife Service, Portland Regional Office

William Wilson	U.S. Environmental Protection Agency, Hazardous Wastes Section, San Francisco Regional Office
Robert Saunders	University of Washington, Department of Ecology
Scott Benson	Northwest Coastal Zone Management Pro- gram
Richard Matthews	Oregon Coastal Zone Management Program
Dave Rick	North Pacific River Basin Commission
Neil Morck	U.S. Bureau of Land Management, Bellingham Office
Jim Lauman	U.S. Fish and Wildlife Service, Office of the Environment, Oregon Regional Office
John Malek	U.S. Army Corps of Engineers, Environmental Office, Seattle Regional Office
Howard Harris	National Oceanic and Atmospheric Adminis- tration, MESA program
Jim Maragesse Marge Elliott	U.S. Army Corps of Engineers, Honolulu Office
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Jim Bottorf	U.S. Fish and Wildlife Service, Endangered Species Team, Olympia, Washington
Frank Newton	Oregon Department of Fish and Wildlife
Floyd Potter	Texas Wildlife Director's Office
Joe Jacobs	Mississippi National Heritage Program
Ann Shapiro, Endangered Species Biologist	Florida Game and Freshwater Fish Commis- sion
Monty Shirts	U.S. Bureau of Mines, Salt Lake City Metal- lurgical Research Center
John Honecker	Mine Safety and Health Administration
Dale Wilkins	U.S. Geological Survey Regional Office, San Francisco
Matt Eliot	California Department of Mines and Geology

Bruce Conrad	U.S. Bureau of Land Management Regional Office, Office of Planning and Coordination, Sacramento
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William Lee	California Public Utilities Commission Environmental Affairs Office
Gary Midkiff	California Department of Planning and Research
Joel Kibbee	Southern California Association of Governments
Richard Sandell	Port of Long Beach
Emil Nurisfo	Pacific Gas and Electric Company Lands Office
Allen Wilke	Pacific Gas and Electric Company
Fred Calder	Florida Coastal Zone Program
Jim Quinn	Florida Coastal Zone Program

Karen Anthony	Department of Environmental Regulations Permitting Office
Bruce Rickey	Alabama Coastal Zone Management Program
Jerry Mitchell	Mississippi Coastal Zone Management Program
William Burke	Louisiana Coastal Zone Management Program
Jim Porter	Louisiana Office of Environmental Affairs
William Longley	Texas Coastal Zone Program
Kay Andrews	Texas Coastal Zone Program
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Ed Dangler	Ocean Minerals Company
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Jay Watson	U.S. Fish and Wildlife Service Regional Office Portland, Oregon
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Edward Davin	National Oceanic and Atmospheric Administration International Decade of Ocean Exploration
Grant DeHart	National Oceanic and Atmospheric Administration Office of Coastal Zone Management
Charles Ehler	National Oceanic and Atmospheric Administration Office of Ocean Resources, Coordination, and Assessment
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Mark Grussendorf	U.S. Bureau of Land Management New Orleans Office
Mary Bartz	U.S. Bureau of Land Management New Orleans Office
Martin Golden	U.S. Bureau of Land Management Los Angeles Office
Irv Marcus	U.S. Bureau of Land Management Los Angeles Office
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Bruce Blanchard	U.S. Department of the Interior Environmental Office
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Blaine Davidson

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Penny Ferreira

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Greg Baker

Donald White

Bill Godwin

John Vetter

Penelope Hansen

John Pullen

Dr. James Lisnyk

Florida Office of Planning and Budget

Alabama Coastal Zone Management Program

Alabama Geological Survey

Mississippi Coastal Zone Management Program

Louisiana Coastal Zone Management Program

Texas Coastal Zone Management Program

Texas Natural Resources Information Center

Rice Center for Community Design and Research

Texas A&M University

Oregon State University School of Oceanography

Florida Atlantic University

University of Rhode Island

Nossaman, Krueger, and Marsh

Ocean Mining Associates

Coastal Environments, Inc.

Oregon Department of Economic Development
Ports Division

Washington Public Ports Association

U.S. Army Corps of Engineers
Office of the Chief Engineer

U.S. Army Corps of Engineers
Water Resources Center

U.S. Environmental Protection Agency,
Office of Solid Waste

Maritime Administration
San Francisco

Maritime Administration
Office of Marine Technology

In addition, the following agencies and organizations have been contacted:

National Oceanic and Atmospheric Administration, Environmental Data Information Service

National Technical Information Service, Computer Search

Smithsonian Science Information Exchange, Computer Search

Marine Technology Society

University of Texas, Department of Economic Geology